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PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

GLASS

AND GLASS MANUFACTURE

BY

PERCIVAL MARSON

CONSULTANT UPON REFRACTORY MATERIALS, ETC.
HONOURS AND MEDALLIST IN GLASS MANUFACTURE

REVISED AND ENLARGED BY

L. M. ANGUS-BUTTERWORTH

F.R.G.S., F.Z.S., F.S.A. SCOT.

(DIRECTOR OF THE NEWTON HEATH GLASS WORKS, MANCHESTER)

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PREFACE

It is a striking fact that although right up to about the beginning of the present century hand methods of making were universal in the glass industry, they have now become almost entirely a thing of the past, except in the making of fine tableware. Glassmaking has now become largely an engineering proposition. For many centuries methods remained practically unchanged in the industry, and it was only about the time of the outbreak of the Great War that interest became thoroughly aroused in the use of automatic machines for glass manufacture.

It will be understood that it was not possible for the manufacturers in Europe to make much progress during the war years. America, on the other hand, was able to develop the mechanizing of her glass manufacture almost without interruption, and drew far ahead of any other nation in this respect.

Shortly after the war American experience and knowledge began to be applied in England and the rest of Europe, and, together with local enterprise and inventiveness, completely revolutionized the glass industry in the course of a very few years. From being an interesting but antiquated handicraft the making of glass has changed suddenly into a most efficient modern industry.

The British Glass Industry owes an immense debt to Professor W. E. S. Turner, of the University of Sheffield, who has played the leading part in providing the scientific background without which the advances of recent years would have been impossible.

In the years prior to 1914 these islands became more and more accustomed to obtaining their glass from abroad. Glass varies enormously in its composition and properties, and in the first days of the Great War it was found that we were ignorant of the nature of glasses essential to the conduct of the war. Before the war the glass apparatus for our research laboratories had been imported largely from Germany; so had lenses for binoculars and field-glasses; so also had the best camera lenses and many other kinds of glass.

Upon the outbreak of hostilities the need for research became vital, for the manufacturer could not move before the scientist had provided the necessary formulae. At this stage Professor Turner created the Department of Glass Technology of the Sheffield University—still the only department of its kind in any university in the world—and founded the Society of Glass Technology, which now ranks among the best scientific bodies of the country, and whose membership of nearly 700 includes firms and individuals in about thirty countries. Perhaps the most important function of the Society is to act as a publishing medium for the research work done in the Department of Glass Technology. The research work already accomplished has been of the utmost value and significance, and is being continued on an expanding scale. The effect on the industry in future years may well be startling, and Professor Turner is the great energizing force behind the movement.

L. M. ANGUS-BUTTERWORTH.

NEWTON HEATH GLASS WORKS,
MANCHESTER.

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GLASS AND GLASS MANUFACTURE

CHAPTER I

HISTORY OF THE INDUSTRY

It was thought until a short time ago that the original home of glassmaking was Egypt, but Sir Flinders Petrie was recently able to state definitely, as a result of his most valuable excavations and researches, that the Egyptians themselves learnt the art from some earlier and external people. It remains that the earliest glass of which specimens now exist came from Egypt. We have records that the making of glass was being carried on there as early as the fifteenth and sixteenth centuries B.C., nearly 3,500 years ago.

The specimens of ancient Egyptian glass which we now possess have been found in tombs. They have little in common with the glass of to-day. Transparent glass was unknown, and the objects made were all of small size. Glass was often used for purposes of decoration, being made into plaques of fused mosaic for inlay. In the later Egyptian glass we see ample evidence of a highly developed sense of form and decoration. In Greece, which produced such wonderful pottery, glass was very rare, and what there was had either been brought from Egypt or was strongly in the Egyptian tradition.

The Romans, who, unlike the Greeks, made considerable use of glass, also became acquainted with the craft through their trading contact with Egypt. A Roman goblet of olive-green glass, which appears of a deep red by transmitted light, is now in Lord Rothschild's collection, and dates from the third or fourth century A.D. It is surrounded by five figures cut in almost complete relief, although all the carving is undoubtedly on the one piece of glass. The glass is mounted on a metal stand and has also a rim of metal.

Some Roman glass found its way to England, though at that time none was made here, and some fine examples have been excavated from tombs in the Thames valley and from near Colchester. It was in Anglo-Saxon times that the art of glassmaking was first introduced into these islands, only to be lost again for centuries after a short and feeble life.

The Saracenic glass of the thirteenth, fourteenth and fifteenth centuries has been termed the most magnificent and decorative to be met within the whole course of the history of glass. The interest of the group is also supreme because of the new departure of the application of solid enamels to the surface of glass. This was an advance on the skill of the Romans, who are not known to have gone beyond the occasional use of opaque paints.

Figure subjects are of frequent occurrence on these enamelled bottles and goblets, and we find polo players and falconers mounted on yellow, pink and white horses; seated figures drinking and feasting or playing on musical instruments, etc. Sometimes we meet with a frieze showing dogs chasing stags and hares (not of the electric kind, however). Birds are frequent as a background—flying geese or long-necked herons; and it is not uncommon to find quaint little fish, with big heads and long fins.

The mosque lamps of Cairo are also part of this great tradition of enamelled glass. They were really lanterns which were hung from the ceilings of the mosques, and the actual oil-containing lamp was a much smaller article inside this grand outer shell.

Upon the break-up of the Roman Empire the centre of the glass industry was transferred to Venice. It appears clear that the Venetians obtained their skill in the craft direct from its early home in the Near East. There is little evidence to show that they were indebted in any but the smallest degree to the Romans. For a long while Venice enjoyed a virtual monopoly and exported glass in increasing quantities to every part of Europe. The trade was concentrated at Murano, an island suburb of Venice. If a craftsman endeavoured to leave Murano the Inquisition had a range of punishments, varying from a term in the galleys to death at the hands of a trained assassin. In this way the workers were discouraged from going to teach their art abroad.

Glass has been made at Venice for at least 700 years, and it has been remarked that in the graceful vessels of endless variety of form, thin and diaphanous, made here, the skill of the glass-blower attains its most complete expression. There is evidence of a guild of glass-blowers in Venice early in the thirteenth century.

The Venetians did an extensive trade with England in wine glasses. On account of the distance and the danger of breakage, these glasses were extremely costly, and were accordingly greatly treasured. Until the middle of the sixteenth century the drinking vessels in everyday use in this country were of pewter or earthenware, glass being considered much too fragile and valuable for any but special occasions.

In 1550 Venetians were induced to settle in London and make drinking glasses. They were housed in London in a hall of the Crotchet or Crutched Friars (*Fratres Sanctae Crucis*), and the King made them liberal monetary grants. Youths were taken into their employ, and in the course of a few years they imparted much of their skill to these native workmen, thus establishing the manufacture.

The most outstanding figure amongst the early foreign glass masters was Jacob Verselyne, who was born in Venice in 1522, and died in England in 1606. A contemporary document tells us that: "Jacob Verselyne within oure Cittie of London hathe to his greate costes and chardges erected and set uppe one ffurneys and set on worke dyvers and sondrie parsonnes for the makynge of drynkynge glasses such as be accustomablie made in the towne of Morano."

A tazza, or shallow goblet, believed to have been made by Jacob Verselyne for Queen Elizabeth, is still preserved in the royal collection at Windsor Castle, and an even finer specimen of his work is now in the British Museum, this latter bearing the inscription: "In God is all my trust." Verselyne was buried at the little Church of Down, in Kent, where the visitor may still see the monumental brass erected to his memory.

Drinking glasses for some time continued to be copied very faithfully from the earlier metal drinking cups which had preceded them.

In Tudor times, the medieval castle, with narrow slits only for windows, was giving place to the more open manor-house. This naturally caused a demand for larger sheets of window glass, and about the same time that the first makers of drinking glasses came from Venice makers of "broad glass" came from Lorraine and settled in this country. The craft of window-glass making progressed side by side with the making of wine-glasses, and for long these were the two main branches of the glass trade. The Lorrainers were said to be the descendants of glassmakers who had settled in Gaul during the Roman occupation.

In 1586 coal began to be used in place of wood, and this had the advantage of giving a higher temperature. At first furnaces were erected in Sussex and other parts of the South of England. The new fuel was naturally only adopted gradually, and it was not until 1615 that the Government prohibited entirely the use of wood. It followed from the use of coal that the industry was obliged to move to the coalfields, leading to the founding of glass works in Manchester, Stourbridge and Newcastle.

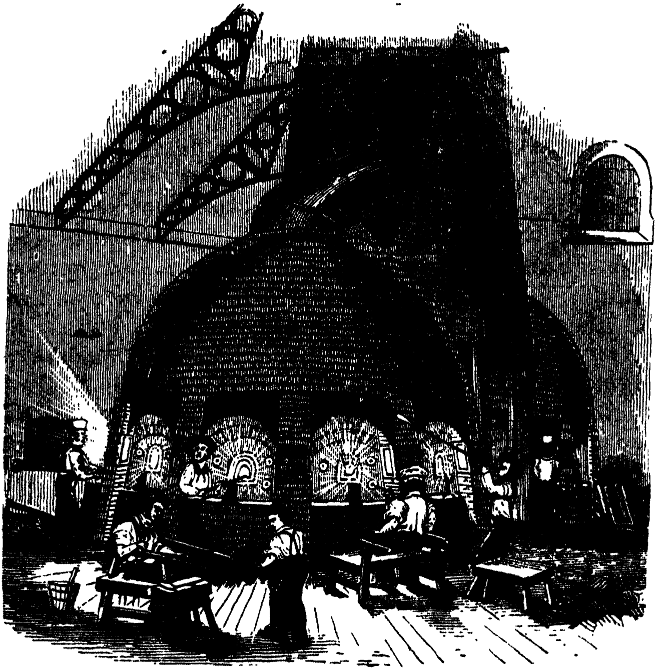

FIG. 1

OLD ENGLISH GLASS-MELTING FURNACES, ABOUT 1800

CHAPTER II

THE CHEMISTRY OF GLASSMAKING AND THE MATERIALS USED

THE term " glass," in a general sense, is applied to the hard, brittle, non-crystalline, transparent, opaque or translucent, vitreous substance which results from fusing silica with active mineral solvents or fluxes, such as the alkalies, earthy bases, or metallic oxides. Silica exists in great abundance, in a free natural state, in the form of flints, quartz, and sand; and in the last-named form it is now most generally used for glassmaking. When sand alkali and lead oxide are heated together to a high temperature, the sand is dissolved by the solvent action of the fused alkali and lead oxide until the whole becomes a molten mass of glass. The solvent action of the alkalis, soda potash, and lead oxide, is very energetic whilst heating is in progress, and the mass boils with evolution of gases until the solution, becoming complete, settles down to a clear, quiescent, molten liquid metal, which is quite soft and malleable, after the nature of treacle. In this condition it is ready for working. The time and temperature necessary for melting such mixtures vary according to the proportions and composition of the ingredients.

Sand (*Silica*), combined with alumina and other oxides, is freely distributed in nature in the form of clays, granites, and felspars, which are also available for use in glassmaking. Originally glass was made by using crushed and ground flint stones as the source for the silica: hence is derived the old name of " flint " glass; but now the large extensive deposits of white sand present a much more convenient and less expensive source, and sand has become universally used. Fine white sand is obtained from Fontainebleau, near Paris; other sources are Lippe, Lynn, Aylesbury, Isle of Wight, Holland, and Belgium.[1] These are the sources preferred by crystal glass manufacturers and makers of fine quality glass, such as chemical ware, pressed glass, tube, cane, and medical bottles, on account of the greater purity of the sand. The commoner varieties of sand from Reigate and Bagshot and even red sand are being used for making the lower grades of glass such as beer bottles and jam jars, where a greater latitude in the chemical impurities present is permissible. Only the best and purest silica sands are used for making cut crystal and optical glasses. In these trades the sand is always cleaned by washing it in water to clear it from any salt, chalk, or other impurities which may possibly be present. The sand, after washing, is heated to redness, or "burnt," in order to burn off any organic or vegetable matter, and when cold it is sifted through a fine screen to take out any coarse grains or lumps. In this prepared state, the sand is ready for weighing out into the proportions desired for mixing with the other materials, and is stored for use in covered wooden compartments situated in or near the mixing rooms, along with the other materials which may be used in the glass mixtures.

The alkalis, potash or soda, or a mixture of both, are commonly used in making glass in the form either of carbonates, sulphates, or nitrates. The soda and potash silicates form very fusible glasses, but they are not permanent, being soluble in water; therefore, they cannot be used alone. In making glassware for domestic use, other bases, such as lead oxide, barium, or lime, have to be added to form more insoluble combinations with the silica or sand.

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[1] *See* "British Glass Sands" (Boswell), "British Glassmaking Sands" (Peddle); papers read at the third meeting, Society of Glass Technology, Sheffield, for further information.

Potash (*Potassium Carbonate*), which before the war was imported into this country by glass makers from Stassfurt, is much prized by crystal glass makers on account of the colourless silicate it forms when fused with the best white sand. It is now very expensive and difficult to get, and is less used on this account. Potash carbonate is very hygroscopic and absorbs much moisture from the air; therefore, it is necessary to keep it within sealed chests while in store.

Potash and soda both have an influence upon the colour of the resulting glasses in which they are respectively used. The potash silicate gives better and clearer glasses than the soda silicate.

Soda Ash (*Sodium Carbonate*) is now more generally used. Being a less expensive form of alkali, it constitutes a base in most of the commoner varieties of glassware. Carbonate of soda is manufactured in England from common salt, of which there are large deposits in the Midlands. This common salt, or chloride of sodium, is treated chemically and converted into the carbonate, in which form it is supplied to the glass manufacturers as soda ash.

Salt Cake (*Sodium Sulphate*) is the form of alkali used in window and bottle glassmaking. In mixtures containing sulphate of soda it is necessary to use a small proportion of carbon in some form, such as charcoal or coal, in order to assist the decomposition of the salt and the formation of the sodium silicate. Sulphate of soda is used in this class of glassware on account of its cheapness. Glasses made from sulphate of soda mixtures are not so clear and colourless as those in which the source of alkali is potash or soda carbonate. On this account, the best crystal glasses cannot be made from sulphate of soda.

Saltpetre (*Potassium Nitrate*) is used in glass mixtures to oxidize the molten metal and improve the colour of the glass. In fusing, it disengages oxygen gas, which purifies the glass while melting, and assists the decolorizers in their action by keeping up an oxidizing condition within the molten mass.

Chili Nitre (*Sodium Nitrate*) is the corresponding soda salt to potash nitre. It is much cheaper, but less pure; it has a similar but not nearly so powerful an oxidising action in the glass as potash nitre. It is exported from Chili, where it exists naturally in a crude state as "Caliche," from which the nitrate is refined by recrystallization.

Boric Acid acts as an acid in glass, as does silicic acid. It renders glass more fusible and brilliant; it has a searching action upon the colouring properties of certain metallic oxides when they are dissolved in the glass. It is an expensive ingredient, but is considerably used in optical and special chemical glassware in replacing a portion of the silicates ordinarily used and in forming borates. It cannot be used in large amounts, as an excess produces glass of a less stable nature.

Borax (*Sodium Borate*) consists of boric acid combined with soda. It is a very useful glassmaking material and is an active fluxing agent. If used in excess in glass mixtures it causes considerable ebullition, or boiling of the metal. In moderate proportions it is used in the manufacture of enamels for glass, as it helps to dissolve the colorific oxides and to diffuse the colouring throughout the enamel mass.

Tincal, and **Borate of Lime,** are other forms in which borates may be introduced into glass.

Limespar (*Calcium Carbonate*). It is an earthy base and is added to the simple alkaline silicates and borates to form insoluble combinations or double silicates of soda and lime. By the use of lime, glasses are rendered more permanent and unchangeable when in use. Lime forms a very powerful flux at high temperatures. The quantity used must be carefully regulated according to the proportion of other bases present; otherwise an inferior or less stable glass may be produced. In excess it causes glass to become devitrified.

Dolomite (*Calcium and Magnesium Carbonates*) is a natural stone which is available for use in making glass in tank furnaces.

Fluorspar (*Calcium Fluoride*) is used in giving opacity and translucency to glass. It can only be used in small amounts, as the presence of any large proportion attacks the clay of the pots, causing serious damage by the sharp, cutting chemical action due to the evolution of fluorine gas.

Lime (*Phosphate of*) is another material which produces opacity and translucency, but does not seriously attack the pots. Bone ash is a form of phosphate of lime, and is procured by calcining bones until all organic matter is consumed.

Barium or **Witherite,** is a very heavy, white powder, and is a form of earthy base available for use in glass-making. It can be used to replace lime, with similar results. By replacing other elements in the glass which are of lower density, barium can be used to increase the density of glass. Like lime it is a very powerful flux in glass at high temperatures. It gives increased brilliancy and little coloration. For this reason it is very useful in the manufacture of pressed glassware, giving a glass which leaves the moulds with better gloss than is found to be the case with lime glasses.

Magnesia and **Strontia** are other bases which are less used in glassmaking.

Zinc Oxide is a base used in the manufacture of many optical glasses. With boric acid it gives silicates of a low coefficient of expansion and special optical values. Used with cryolite, it forms a very dense opal suitable for pressed ware. It is rather more expensive than the other bases used.

Cryolite (*Sodium Aluminium Fluoride*) is a natural opacifying ingredient used in making opal glasses. It consists of a combination of the fluorides of aluminium and sodium, and is one of the most active fluxes known to glass and enamel makers. Its cutting chemical attack on the fire-clay pots is very intensive. It is imported from Greenland. A synthetic or manufactured form of cryolite is known, which is a little cheaper than the natural variety and gives similar results in opacifying glass.

Alumina. This is sometimes present to a small extent in glass makers' sands. As such it is not a dangerous impurity. It exists in combination with silica and potash to a large extent in felspars, china clays, and granites. Alumina, when used, has a decided influence upon the viscosity and permanency of glass. In large proportions it noticeably diminishes the fusibility of glass, and makes it more or less translucent. Owing to the refractory nature of alumina it is with difficulty that it can be diffused in alkaline silicates, borates, or lead silicates; consequently any considerable proportion present in glass may cause cords or striae, which are objectionable defects in the glass.

Red Lead or **Minium** (*Lead Oxide*) is much used in the manufacture of enamels, table glassware, and heavy optical glass. It gives great brilliancy and density to all glasses in which it is used, but if used in excess the glass is attacked readily by mineral acids and becomes unstable. Red lead is a powerful flux, even at low temperatures, and forms the chief base in making best crystal ware and enamels. The red oxide of lead used by glass manufacturers is a mixture of the monoxide and peroxide. Glass manufacturers, in buying red lead, should realize that it is the peroxide present which is the active oxidizing agent, and that at least 27 per cent should be present. A dull, dark red oxide shows a low percentage of peroxide: a bright, orange red a high percentage. Impure red oxides of lead may be adulterated with barytes, finely divided metallic lead, or water. Such impure varieties should be avoided. The red oxide of lead is preferred to the other oxides and forms of lead for glassmaking, on account of its greater oxidizing action, which is desirable in producing crystal glassware.

Tin and **Antimony** (*Oxides of*) are used as opacifiers. When used they generally remain suspended in a finely divided form in the glass. Used in small quantities they have a favourable influence in the development of ruby-coloured glasses.

Manganese, Arsenic, and **Nickel** are used in glassmaking as "decolorizers," which will be treated in a later chapter.

Cullet. In all glasses a proportion of "cullet," or broken glass scrap, is used. This cullet is usually of the same composition as the glass mixture or "batch." The use of cullet facilitates the melting, and assists in giving homogeneity to the resultant glass by breaking up the cords and striae which tend to develop in most glasses.

In the manufacture of the commoner varieties of bottle glass **Basalt** and other igneous rocks are crushed and used. These are naturally occurring silicates containing lime alumina, alkalis, iron, and other elements in varying proportions. They are used more on account of their cheapness, and produce dark, dirty-coloured glasses, which in the case of common bottles are not objected to. In some instances iron manganese or carbon is added to produce black bottle glass.

Of the various silicates used in glassmaking, the silicate of alumina is the most refractory. The silicates of lime and barium are rather refractory, but under a strong heat and in the presence of other silicates they can be readily formed. The silicates of the alkalis, lead, and many of the other metals are formed at much lower temperatures. In the case of the silicate of iron, manganese, or copper, a strong affinity is shown between the metal and the silica, and a black or dark-coloured slag with a very low melting point is formed. Such slags are very active in corroding the fire-clay masonry and pots of the furnace.

No single silicate is entirely free from colour. Each gives a slight distinctive coloration, the lead silicate being yellowish and the soda silicate greenish, but by the judicious mixture of different silicates and the use of decolorizers, such as manganese, nickel, etc., compound silicates are obtained, giving less perceptible colours or crystal effects. In optical glassmaking the use of the ordinary decolorizers is not permissible, and the purity of the materials used becomes the most important factor.

The mixture of the various raw materials used in making glass is termed a "batch." The mixing was formerly done by hand, but nowadays mechanical batch-mixers are used. The materials are first weighed out in their correct proportions by means of a platform weighing-machine. As they are weighed out, one by one, they are introduced into a rectangular wooden arbour or box, large enough to hold the whole unit weight of the batch and from this are transferred to the electrically-driven mixer. All the coarse materials are reduced or crushed to a size not coarser than granulated sugar. By sieving and turning the batch several times a thorough mixture of the ingredients is obtained. A few ounces of manganese dioxide are then added, according to the unit weight of the batch weighed out, and the proportion of decolorizer necessary, which varies according to the heat of the furnace and the amount of the impurities present.

The whole batch is then put into trucks and conveyed to the glass house, where the furnace is situated. Here it is tipped into another arbour or box in a convenient position near to the melting pot, and, a proportional quantity of "cullet" being added, the mixture is then ready for filling into the pots. The stopper of the pot mouth is taken away and placed aside, and a man shovels the mixture or batch into the hot pot until it is full. He then replaces the stopper, and, after a few hours, when the first filling has melted and subsided, another filling of batch into the pot takes place until it becomes full of glass metal in its molten state. The batch melts with considerable ebullition, owing to the chemical reactions taking place under the heat of the furnace, giving off at the same time large quantities of gas. By the evolution of these gases the batch shrinks in volume, so that it becomes necessary to fill a pot more than once with the batch before it becomes full of molten metal. The capacity of the pots varies between 250 and 1,200 kilogrammes, according to the type of glass and nature of the goods made.

Much care is required in mixing and sieving batches containing lead and other poisonous ingredients, to prevent the inhalation of the dust by the mixer. Therefore, where such materials are used, exhaust fans and ventilating ducts should be provided and fitted in the mixing rooms. A suitable respirator should be worn by the mixer in charge to prevent any absorption into his system of the poisonous dust. Cases of poisoning are not unknown, but these are due to gross carelessness. A small, regular, weekly dose of Epsom salts should be taken by the mixers who have to prepare lead batches. This salt tends to remove any lead salts absorbed in the system by converting them into insoluble lead sulphate.

CHEMICAL FORMULAE AND MOLECULAR WEIGHTS OF GLASSMAKING MATERIALS

Materials.	*Formulae.*	*Molecular Weight.*
Alumina	Al_2O_3	102
Antimony	Sb_2O_3	287
Arsenic	As_2O_3	197
Barium	$BaCO_3$	197
Bismuth	Bi_2O_3	468
Borax	$Na_2B_4O_7 + 10H_2O$	382
Boric Acid	H_3BO_3 (or B_2O_3)	62
Carbon	C	12
China Clay	$2SiO_2Al_2O_32H_2O$	258
Chrome	Cr_2O_3	153
Cobalt	Co_2O_3	105
Copper (Red Oxide)	Cu_2O	143
(Black ,,)	CuO	79
Cryolite	$6NaFAl_2F6$	210
Dolomite	$CaOMgO2C_2$	184
Felspar	$K_2OAl_2O_36SiO_2$	556
Fluorspar	CaF_2	78
Gold Chloride	$AuCl_32H_2O$	339
Iron	F_2O_3	160
Lead (Red)	Pb_3O_4	683
Lime	CaO	56
,, (Phosphate of)	$Ca_3(PO_4)2$	310
Limespar	$CaCO_3$	100
Magnesia	$MgCO_3$	84
Manganese	MnO_2	87
Nickel	NiO_2	75
Potash (Hydrated)	$K_2CO_3(2H_2O)$	174
,, (Calcined)	K_2CO_3	138
Saltcake	Na_2SO4	142
Saltpetre	KNO_3	101
Sand	SiO_2	60
Soda Ash	Na_2CO_3	106
,, (Fluoride of)	NaF_2	61
,, (Nitrate of)	$NaNO_3$	85
Tin	SnO_2	150
Uranium	UO_2	272
Zinc	ZnO	81

CHAPTER III

THE CHEMICAL AND PHYSICAL PROPERTIES OF GLASS

THE commonest and best known property of glass is transparency, but it is often made merely translucent or even entirely opaque. When subjected to a gradually increasing temperature, glass becomes softened, and whilst hot it is plastic, ductile, and malleable, in which state it can be cut, welded, drawn, or pressed. A thread of glass can be drawn so thin and fine that it can be twisted and bent to a remarkable extent, showing that glass is flexible.

The above properties shown by glass while softened under heat permit it to be shaped and formed by a variety of methods, so that in the manufacture of the different kinds of glass we find goods pressed, blown, drawn, moulded, rolled and cast from the hot metal. Upon cooling, the form given to them is retained permanently.

Another property of glass is its conchoidal fracture and liability to crack under any sudden change of temperature. Advantage is taken of this peculiarity in dividing or cracking apart glass when necessary, during the stages of the manufacture of any glass article.

If a glass worker, in making an article of glass, desires to detach or cut apart certain sections, he applies a cold wet substance, such as an iron file wetted with water, to any portion of the hot glass, which causes it to fracture at the point of contact with the cold metal, and a slight jar is then sufficient to break the two portions apart. This method of chilling heated glassware to divide it is applied in the mechanical process of cutting up the long cylindrical tubes of glass into short sections for use as miner's safety-lamp chimneys. Wherever it is desired to cut them through, a narrow section or line round the cylinder is first heated by a sharp, hot pencil of flame projected from a burner against the rotating cylindrical tube of glass at equidistant short sections, and the divisions chilled by contact with a cold, steel point, or the heated area may be gently scratched with a diamond point, when a clean,

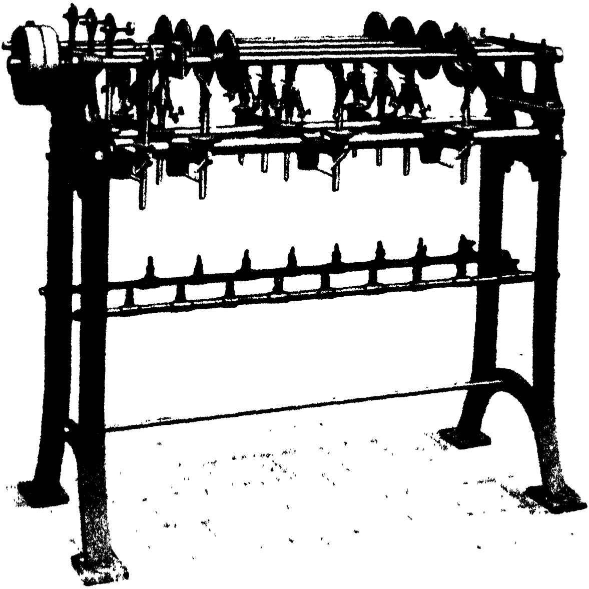

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FIG. 2

HORIZONTAL CRACKING-OFF MACHINE

sharp fracture results exactly where the chill or scratch has been applied and spreads round the whole circumference in a circle, giving neat, clean-cut divisions. In cutting narrow tube and cane, the fracture caused in the structure of the glass by scratching its surface with a steel file or diamond is sufficient to cause it to break apart without the application of heat.

A piece of hot glass will weld on to another piece of hot glass of similar composition. The glass maker uses this method of welding for placing handles on to jugs, etc., during the process of making table glassware.

The density of glass varies according to its composition. Certain classes of lead, and thallium glass for optical work, are of very high density. The specific gravities of such glasses may vary from 3·0 to well over 4·0. In soda-lime glasses the density is less and approaches 2·4. Ordinary crystal glass approximates to a specific gravity of 3·1.

The elasticity and thermal coefficient of expansion of glass can be regulated within normal limits. Glasses are now manufactured which can be perfectly sealed to copper, iron, nickel, and platinum wires.

Glass, if kept heated for any length of time at a temperature just short of its softening or deformation point, becomes devitrified and loses its transparency, turning opaque and crystalline. In this state it has much of the nature of vitreous porcelain and is totally different to manipulate, being tough and viscid on further heating. This devitrified state may occur during glassmaking, where the metal is allowed to remain in the pot or tank furnace for a considerable time under low temperature. Small stars or crystals first develop throughout the glass and continue to grow until it becomes a stony, white, opaque, vitreous mass. " Réaumur's Porcelain " is a glass in a devitrified state, and is used for pestles and mortars, devitrified glass being less brittle than ordinary glass and similar to vitrified porcelain.

Glass can be toughened to an extent which is surprising. Bastie's process consists of plunging the finished glass article whilst hot into a bath of boiling oil, which toughens the glass so much as to make it extremely hard and resistant to shocks, losing most of its brittle nature. Strong plates of glass are produced by a process of toughening under pressure. These plates of glass are used for ship porthole lights and in positions where great strength is required. Toughened or hardened glass is of great value in the production of miner's lamp glasses and steam-gauge tubing. Glass, when hardened, is difficult to cut even with the diamond, and difficulty is experienced in finding suitable means of cutting it into shapes to suit commercial requirements.

"*Prince Rupert drops,*" or tears, exhibit the state in which unannealed glass physically exists. These are made as a curiosity by dropping a small quantity of hot metal from the gathering-iron into a bath of water and then taking the pear-shaped drops out quickly. These pear-shaped drops of glass will stand a hard blow on the head or thicker portion without breaking, but, if the tail is pinched off or broken, the whole mass crumbles and falls to powder. This well illustrates the latent stresses or strains apparently in a state of tension and thrust within the structure of unannealed glass.

Glass is not a good conductor of heat. This accounts for the necessity of slow cooling or annealing glassware, and also applies when re-heating glass, which must be done slowly and evenly to allow time for the conduction of the heat through the mass gradually. Glass is a non-conductor of electricity, and is used to a considerable extent in the electrical trades for insulation purposes. Most glasses are attacked slightly, but not readily, by water and dilute mineral acids. Continued exposure to a humid atmosphere causes slight superficial decomposition, according to the stability and chemical composition of the glass. Old antique specimens of glass show the superficial decomposition caused by long, continuous exposure to atmospheric moisture. Many antique specimens have been known to collapse instantly upon being unearthed. The first change in antique glass is exhibited by a slight iridescence forming on the surface, gradually increasing towards opacity; afterward disintegration sets in, until it finally collapses or crumbles to powder. Glasses high in lead are readily attacked by the acid vapours met with in the atmosphere, but the harder soda-lime glasses are more resistant. An excess of boric acid, soda, or potash also renders glass subject to disintegration and decay.

Hydrofluoric acid attacks all silicate glasses, liberating silicon fluoride. Use is made of this acid reaction in decorating glasswares in "etching," by exposing the surface of glass to the fumes of hydrofluoric acid gas in some form.

The most permanent glasses are those containing the highest proportion of silica in solution, but the available heat necessary to decompose such highly silicious mixtures is limited by the present known refractory materials which can be procured for constructing the furnaces. Quartz glassware is a highly silicious glass. It is now made and used in the manufacture of special chemical apparatus and laboratory ware such as crucibles, muffles, etc., which have to withstand severe physical and chemical tests. This quartz glass possesses remarkable features in its low coefficient of expansion and resistance to heat changes. It is highly refractory. Articles made of this glass can be raised to red heat and plunged directly into cold water several times without fracturing. Several varieties of quartz glass are now manufactured, and a new field for investigation is presented in applying the features and properties of this glass for use in chemical processes.

In a purely physical sense glass is a super-cooled liquid, the silicates are only in mutual solution with each other, and they appear to be constantly changing. Glass cannot be described as a homogeneous or definite chemical compound. Many of the after-effects and changes which occur in glass, and the formation of crystals in the devitrification of glass, tend to prove the above assertion. The colour-changes which take place when ruby and opalescent glass is re-heated, and even the change in colour of glass going through the lehr, cannot be explained unless in the above sense of viewing these remarkable changes. Glasses with an excess of lime in their composition are more subject to devitrification than lead glasses or those of moderate lime content constructed from more complex formulae. The presence of a small proportion of alumina in glass prevents this tendency to devitrification and ensures permanency. Those glasses which have the highest silica content, and which have been produced at the highest temperatures, show the greatest stability in use. Bohemian glasses of this type contain as much as 75 per cent silica, and are produced in gas-fired regenerative or recuperative furnaces, where the heat approaches 1,500° Centigrade. Such glass is much sought after for enamelling on, being harder and less easily softened by the muffle heat firing on the enamels used. Taking two corresponding glasses of the same basicity, or proportion of silicic acid to the bases present, those formulae which have the greater complexity of bases produce the more fusible glasses. A multiple of bases constituting a more active flux than a single-base content, it follows that a compound mixture of silicates fuses or melts at a lower temperature than the respective simple silicates would. These facts are useful in constructing commercial formulae for glasses.

Glasses containing lead oxide as an ingredient are subject to reduction when exposed to flames of a carbonaceous nature. The carbon partially reduces the lead oxide to its metallic state, forming a black deposit. On this account, lead glasses cannot be used in blowpipe working with the ease with which soda-lime glasses can be worked, without reduction taking place. English crystal glass, which contains a high percentage of lead, is usually melted in hooded or covered pots to prevent the carbonaceous flames of the furnace reducing the lead and otherwise destroying the clearness of the glassware. Soda-lime glass and others without the presence of lead can be melted in open pots without any fear of reduction. Modern gas-fired recuperative furnaces, in which more complete combustion of the carbon takes place, can now be used for melting lead glasses in open pots, thus presenting a great saving in the fuel required to melt and produce such glass, besides permitting the use of a cheaper form of pot. This cannot be done with the ordinary English coal-fired furnaces.

Advantage is taken of the reducing action of the coal-gas flame when producing lustre and iridescent glassware. A small proportion of easily reducible metal, such as silver or bismuth, is introduced into the glass and first melted under oxidizing conditions. It is then reduced in after-working by flaming, which deposits the metal in a thin sheen upon the surface of the glass, where it comes in contact with the reducing flames. An example of this effect is shown in Tiffany lustre ware, in which silver chloride is used and reduced within the glass, giving a pretty, coloured iridescence on the surface, due to the reflection of light from the particles of metal deposited under the surface.

"Aventurine" is a form of glass in which copper and iron oxides are introduced under reducing conditions during melting. The glass is then allowed to cool slowly. The metallic copper tends to separate out in small spangled crystals, which give a pretty, sparkling effect. The use of strong reducing agents with very slow annealing is necessary to produce this effect. Copper and gold ruby-coloured glass presents other instances of partial precipitation of the metal by reduction within the glass. According to the extent of reduction, the glass ranges in colour from yellow to ruby and to brown.

The manganese silicate is readily affected by oxidizing or reducing conditions, the purple colour being present under oxidizing influences and a greenish-grey colour under reducing conditions.

The colour of glass is gradually affected in course of time by sunlight. This change in colour is often noticeable in old windows, the glass having developed a yellowish-green tint in course of time from the action of the solar rays.

Glass which has been incompletely fused or not sufficiently melted to give a complete solution of the materials present is in a weakened state of cohesion and is liable to disintegration. The presence of undecomposed sulphates, chlorides, or borates in the glass also tends to early disintegration. A continual exudation and crystallization of salt takes place upon the surface until the glass wholly disintegrates to a white powdered salt.

Glass is a poor conductor of heat. When a piece of glass has been expanded under the influence of heat, and is rapidly cooled, the superficial outer portions become intensely strained and contracted upon the interior portions, which retain the heat longer. Under these conditions of cooling, glass is apt to "fly," or collapse and fall to pieces, owing to the outer portions giving way under the great strain. These stresses or strains are relieved in the process of annealing, under which they are gradually eased by a slow and regular cooling from the heated condition. Certain glasses, the composition of which shows considerable differences in the density of the respective bases present, are more subject to this defect than those in which the bases are of more even density and homogeneous in character. Such glasses should be "de-graded" and re-melted in order more thoroughly to diffuse and distribute the denser portions throughout the mass. In de-grading glass, the hot glass is ladled out and quenched in cold water, dried, and re-used as "cullet."

CHAPTER IV

THE COMPOSITION OF THE DIFFERENT KINDS OF GLASS

THE composition of glasses may be simple, compound, or complex, according to the number of bases or acids which may be present in the mixture.

The Simple types of glass are exhibited in the soda silicate, potash silicate, and lead silicate. The two former silicates are of most industrial value.

Soda Silicate is made from a fusion of 100 parts of sand with 50 parts of soda carbonate and 5 parts of charcoal. The charcoal is added to facilitate the decomposition. The fused mass when cool is transparent and of a pale, bluish, sea-green colour. Upon boiling it in water it dissolves and gives a thick viscid solution called "Water Glass." This is extensively used in the various arts and manufactures. Textile fabric and woodwork saturated with this solution and dried are rendered fireproof. In the manufacture of artificial stone it forms, with lime and other basic oxides, very stable cements. Mixed with silicious fire-clay or ganister it forms the well-known fire cements for repairing the cracks in fire-clay retorts, muffles, etc. Water glass is also used in soap and colour making, and for preserving eggs.

Potash Silicate is less used, being more expensive. It is produced from a fusion of 100 parts sand, 60 parts potash carbonate, and 6 parts charcoal.

Lead Silicate is composed of 100 parts sand and 66 parts of red lead fused together. This silicate is mostly used in the manufacture of soft enamels and artificial gems, and goes under the names of "Rocaili flux," "strass metal," and "diamond paste."

There is another form of soluble glass which is a combination of the soda and potash silicates. This is really a double silicate and may be produced by fusing sand 100 parts, soda carbonate 25 parts, potash carbonate 30 parts, and 6 parts of charcoal. This silicate is used in soap making. Soluble glass can also be formed by using sulphate of soda as the alkali. In this case, a larger proportion of the alkaline salt has to be used, also a larger amount of carbon, in order to complete the decomposition of the sulphate. A mixture of sand 100 parts, saltcake 70 parts, and carbon 16 parts would produce sodium silicate. The boron silicate and borate of alumina are two other forms of soluble glass used in their simple states.

The Compound Glasses may be flint or crystal glass, soda-lime glass, Bohemian glass, pressed glass, and sheet glass. These are the general types of glasses used in the manufacture of domestic glasswares.

Crystal Glass, which is a silicate of lead and potash, is made from best sand 100 parts, red lead 66 parts, potash carbonate 33 parts, cullet 50 parts, to which a small proportion of potash nitre, arsenic, and manganese dioxide is added. The bulk of English cut-glass table ware and fancy goods are made from this type of glass. It gives very brilliant and colourless results, more especially when cut and polished. A second-rate quality of crystal glass for table ware may consist of a silicate of lead and soda, as follows: sand 100 parts, red lead 66 parts, soda carbonate 25 parts, cullet 50 parts; with small proportions of Chili nitre, arsenic, and manganese.

Bohemian Glass is made from sand 100 parts, potash carbonate 35 parts, lime carbonate 15 parts, cullet

50 parts; with small proportions of potash nitre, arsenic, and manganese dioxide. This type of glass is used mostly by Continental manufacturers for chemical ware, and table and mirror glass. It is a hard, brilliant, and stable glass, very suitable for enamelled glassware. It is a silicate of potash and lime.

Pressed Glass consists of sand 100 parts, soda carbonate 50 parts, barium carbonate 15 parts, cullet 50 parts; together with soda nitre, arsenic, manganese, and cobalt. This is used by manufacturers of pressed glass table ware or moulded ware. It is a silicate of soda and barium, the barium having a direct influence in giving a good surface to the pressed goods.

Crown Glass consists of a silicate of soda and lime: sand 100 parts, soda carbonate 36 parts, lime carbonate 24 parts, soda sulphate 12 parts, cullet 50 parts; with traces of manganese and cobalt. This glass is used for making sheet window glass by the crown, disc, and cylinder methods

Plate Glass is a silicate of soda and lime: sand 100 parts, soda sulphate 55 parts, limestone 30 parts, coal or anthracite 5 parts; with traces of nickel oxide, cobalt, or antimony oxide. This is used for cast plate glass, rolled plate, cathedral glass, window and mirror glass.

The Complex Glasses may be described as those in which more than three bases are introduced, and constitute such types of glasswares as bottles, thermometer tubes, chemical ware, etc.

Common Bottle Glass may be described as an example of complex formulae. Common bottle glass is made from a silicate of soda, alumina, lime, magnesia, and iron, as follows: common sand, containing iron and alumina, 100 parts; greenstone or basalt (a silicate of alumina, iron, lime, magnesia, and potash), 25 parts; dolomite limestone (magnesia and lime), 30 parts; sulphate of soda, 35 parts; carbon, 5 parts. Felspathic granites may be also used in such glasses.

Bottle glasses require intense heat to melt, and are usually dark in colour when made from igneous rocks, owing to the large amount of colorific oxides present in such materials. These dark colours are not objected to in bottles for stout, wine, and beer.

It will be noticed these formulae cover a wide range, from the best table glass to the commonest dark bottle glass. Besides these, opal, opalescent, and fancy glasses are made, in which arsenic, tin, alumina, antimony, zinc or barium oxides or borates, phosphates, and fluorides may enter into the compositions.

Glass makers' recipes vary considerably in the proportions of the various materials used, according to the locality and the type of furnace used. Generally, it will be found that, where a gas-fired furnace is in use, a larger proportion of sand can be used and a cheaper metal produced.

The metals produced in covered pots are usually softer and contain more lead and fluxes than those produced in open pots. In using open pots the heat of the furnace has direct access to the surface of the metal therein. In the case of covered pots, the heat has to be conducted through the cover of the pot, which retards the heat to a certain extent. On this account, softer mixtures are used in covered pots.

CHAPTER V

COLOURED GLASS AND ARTIFICIAL GEMS

In colouring glass, any one or several of the following colorific oxides may be used. They are added to the batch before fusion. Varying proportions are added, according to the depth of the colour desired. Occasionally the colour is influenced by the nature and composition of the rest of the batch. In some instances several colouring oxides are used. In this way many delicate tints are obtained; in fact, there are but few colours that cannot be produced in glass.

For Green Glasses the following oxides may be used: chromium oxide, 2 to 6 per cent of the batch ; black oxide of copper, ·5 to 3 per cent ; red iron oxide, ·5 to 1 per cent ; or a mixture of two or three of the above oxides in less proportions. Salts of chromium, copper, or iron may be used as the carbonates, sulphates, and chromates.

For Blue Glasses, cobalt oxide, ·1 to 1 per cent of the batch ; zaffre blue or smalts, 1 to 3 per cent ; nickel oxide, 2 to 4 per cent ; iron oxide, 1 to 2 per cent ; black oxide of copper, 2 per cent.

For Violet and Purple, manganese oxide, 2 to 4 per cent of the batch.

For Rubies, red oxide of copper, gold chloride, purple of cassius, antimony oxysulphide, selenium metal in small proportions.

For Yellows, uranium yellow, 4 to 6 per cent of the batch ; potassium antimoniate, 10 per cent ; carbon, 6 per cent ; sulphur, 5 per cent ; ferric oxide, 2 to 4 per cent. Silver nitrate and cadmium sulphide are also used.

Black Glass is obtained from mixtures of cobalt oxide, nickel oxide, iron oxide, platinum and iridium. Many very dark or black bottle glasses are obtained by using basalt, iron ores, or greenstone in a powdered form, added to the batch ingredients.

White Glasses or **Opal** are obtained by using phosphate of lime, talc, cryolite, alumina, zinc oxide, calcium fluoride, either singly or in double replacements of the bases present in the glass batches.

Many of the colouring oxides give distinctive colours to glass of different compositions; also the resulting colours may vary with the same colouring ingredient, according to reducing or oxidizing meltings. Thus, in a batch of reducing composition, red copper oxide gives ruby glass, but in oxidizing compositions the colour given is green or bluish-green. Iron oxide in an oxidizing batch gives a yellow. In the reducing batch it gives bluish or green results. Manganese is similarly affected.

Many colouring oxides give more brilliant tints with glasses made from the silicates of potash and lime than if used in glasses composed from silicates of lead and soda. For many colours the lead glasses are preferred. In colouring the batches, the colouring oxides must be intimately mixed with the batch materials before fusion, more especially in the preparation of the pale tints, where only small quantities of colouring are necessary. It is a well-known fact that careful mixings give good meltings, for then the materials are more evenly distributed and uniformly attacked during the melting. Careful and exact weighings are necessary when using colorific oxides, and a pot is kept for each respective colour melted, so that the different colours and crystal glasses do not get contaminated with each other. When open pots are used for colours, the colour pots should be kept together in one section of the furnace, so that whilst melting, especially during the boiling up of the batches, the colours do not splash over into the other pots containing crystal metal.

As a rule, smaller pots are used for coloured glass; generally they are only a third of the size of crystal melting pots. When this is so, they are set together under one arch of the furnace, and the workman informed which pots contain the respective colours. All colour cuttings and scraps should be kept separate from other cullet for re-use. Coloured glasses are expensive, and no waste of glass should be permitted.

Artificial Gems. In the manufacture of the glasses for imitation "paste" jewels, every effort is made to procure pure materials and colorific oxides. The base for making artificial gems is a very heavy lead crystal glass termed "**Strass paste,**" which gives great brilliancy and refraction. The composition of such a paste would be: best white sand 100 parts, pure red oxide of lead 150 parts, dry potash carbonate 30 parts. These should be thoroughly melted until clear and free from seed, and the molten mass ladled out of the pot and quenched in cold water, or "de-graded." This assists in making the paste homogeneous. After repeated melting and de-grading, the paste or cullet is collected, dried, and crushed for use in making the coloured pastes. Usually, this strass metal is melted in small, white porcelain crucible pots holding about 5 to 10 kilogrammes of the metal and heated in a properly regulated gas and air injector furnace. The coloured paste is kept in fusion for a whole day, after which it is slowly cooled and annealed within the pot, and the gems cut from the lumps of glass thus obtained. The following are some of the compositions used in the preparation of the respective gems.

Opal. Powdered strass paste, 1,000 parts; white calcium phosphate, 200 parts; uranium yellow, 5 parts; pure manganese oxide, 3 parts; antimony oxide, 8 parts.

Ruby. Powdered strass paste, 1,000 parts; purple of cassius, 1 part; white oxide of tin, 5 parts; antimony oxide, 10 parts.

Beryl. Powdered strass, 1,000 parts; antimony oxysulphide, 10 parts; cobalt oxide, ·25 parts.

Amethyst. Powdered strass glass, 1,000 parts; purest manganese oxide, 8 parts; pure cobalt oxide, 2 parts.

Emerald. Powdered strass glass, 1,000 parts; green chrome oxide, 1 part; black copper oxide, 8 parts.

Sapphire. Powdered strass glass, 1,000 parts; pure cobalt oxide, 15 parts.

Topaz. Powdered strass glass, 1,000 parts; antimony oxide, 50 parts; uranium yellow, 10 parts.

Garnet. Powdered strass glass, 1,000 parts; antimony oxysulphide, 100 parts; gold chloride in solution, 1 part; pure manganese oxide, 4 parts.

Turquoise. Powdered strass glass, 1,000 parts; cobalt oxide, ·5 parts; black copper oxide, 10 parts; white opal glass, made with tin oxide, 200 parts.

After suitable pieces of glass of the requisite tints are obtained, they are cut and ground on a lapidary's wheel, then polished, engraved, and set as gems.

Artificial Pearls are now cleverly made in glass. A tube of the requisite size made of translucent or opal glass is cut into small sections, which are heated on a tray to softening point whilst set in a rotatory movement. As the heat increases they gradually melt in and seal at the openings, when they are removed from the tray and sorted.

CHAPTER VI

DECOLORIZERS

DECOLORIZERS are the agents employed by the glass maker to neutralize or subdue the objectionable tints given by the colouring action of small traces of iron oxide, which exists as an impurity present in the materials used, or otherwise becomes accidentally admixed during the process of the manufacture of glassware.

The small additions of manganese dioxide, arsenic, nitre, nickel oxide, selenium, antimony oxide, etc., to glass batches may be considered as decolorizers. The most commonly used of these materials is manganese dioxide, so the action of this material will be explained. Every glass maker finds that one or other of the raw materials he uses may contain impurities. It is seldom that glass makers' sand can be obtained that does not contain traces of iron oxide present as an impurity. Again, the cullet collected from the glass house often contains iron scale or rust from the blowing-irons, which firmly adheres to the glass and gets admixed with the batch for re-melting. The presence of even very small traces of iron in glass becomes evident as a pale sea-green tint when viewed through any thickness of glass. The chemical action of the glass upon the walls of the pot is continually dissolving a minute quantity of iron from the fire-clay and diffusing it throughout the metal, giving it a tendency to the pale-green tint.

To subdue or neutralize this objectionable tint in the glass, the glass maker uses certain metallic oxides which give delicate counter-tints. Only those glasses which are made from the purest materials can be decolorized to become sufficiently clear to use in making the best table glassware. In optical glassware, where the use of manganese is not permissible, the greatest care has to be taken in the selection and testing of the materials to be used. If manganese oxide be used in making optical glass, although the eye may not be sensitive enough to observe the actual colour absorption, a glass is produced in which the solar rays are obstructed, and much less light is transmitted by the glass when used as an optical lens or prism. Therefore, the optician avails himself of those glasses which have not been decolorized as being more satisfactory for his purpose, as more light is transmitted by such glasses.

Apart from the pale sea-green tint given to glass by the presence of small traces of iron, certain of the silicates themselves produce natural colours. The soda silicate present in soda-lime metal tends to give a pale bluish-green tint when viewed through any thickness of glass. The lead silicate has a yellowish hue. Each of these influences has to be counteracted if clear crystal glass is desired. The decolorization of glass by manganese dioxide depends upon the purple tint it gives to glass. This purple colour, being complementary to the pale green colour given by the presence of iron, serves and acts as a counter-tint, and by the absorption of the green light a less perceptible colouring is produced. In the case of the decolorization of glass, we get the red and blue of the purple subduing the blue and yellow or green tint given by the iron. But certain other factors are necessary. The purple colour from manganese oxide is given only to glass in the presence of oxidizing agents; and in the absence of sufficient oxidizing agents in the glass batch, the purple manganese colour is unstable and its action as a counter-tint is lost. Therefore, the glass maker uses strong oxidizing agents in his glass mixtures for crystal effects, usually in the form of potassium nitrate and red lead, which liberate oxygen. Whilst undergoing decomposition in the glass melt, the presence of this free oxygen keeps the manganese used in a higher state of oxidation, and gives the necessary purple coloration. It is also evident that, if the glass melting in the pot is kept at a high temperature for any considerable length of time, this period of oxidation cannot last, and, after all the free oxygen gas has been evolved, any further heating tends to turn the glass greenish again or of poor colour, by the conversion of the manganese into the lower state of oxidation in which the purple colour is not evident. If by chance the glass maker has added too much manganese to the glass, and the purple colour becomes too evident, he resorts to the use of a small amount of carbonaceous reducing agent, such as a piece of charred wood or potato, which he plunges or pushes to the bottom of the pot by means of a forked iron rod or pole, where it vaporizes, giving off moisture and carbonaceous gases, which reduce the manganese purple colour to a lower oxidized colourless state, and in a very short time the excess of purple colour has disappeared and the glass appears colourless.

Much of the success of crystal glassmaking depends upon the proper adjustment of the decolorizers used, and upon obtaining the best colourless effect. The quality of the manganese dioxide is important; only pure manganese dioxide should be used. In many cases the mineral ore, pyrolusite, is used on account of its cheapness. This is objectionable, as much iron may be present in the ore, when its use as a remedy is worse than the defect. The necessity of taking advantage of the services of a consultant chemist here becomes apparent, for, if glass manufacturers would only have their different consignments of materials examined and tested from time to time, many of the disappointments and difficulties experienced by them at present would be obviated. A considerable saving in the cost of batch materials can be made by the judicious selection of more suitable qualities in preference to inferior or adulterated varieties. In many cases, a chemist can substitute for certain of the expensive batch materials other cheaper materials introducing the same elements and still retain the same quality in the glass produced.

CHAPTER VII

THE REFRACTORY MATERIALS USED

Of the greatest importance to the glass manufacturer are the refractory materials upon which the life of his furnace and pots depends. A few notes giving a description of them and dealing with the manufacture of the fire-resisting blocks used in building the furnaces will therefore have usefulness.

The chief and most generally used of such materials are the fire-clay goods. The best known deposits of fire-clays in this country are those in the Midlands, Stourbridge, Leeds, and Glasgow districts. In each of these districts the mining of fire-clays and the manufacture of fire-resisting goods for furnace work forms an important industry. The theoretical composition of a true fire-clay would be a double silicate of alumina, and in this pure state it would be of a very refractory nature. But, naturally, fire-clays show the presence of other bases, such as iron, lime, magnesia, titanium, and alkalies, which, if present to any appreciable extent, lower the degree of resistance to heat or refractoriness of the clay. These other bases may be considered as impurities or natural fluxing agents. The characteristics of a highly refractory clay suitable for glass manufacturers' requirements would be: (*a*) that such a clay should show no signs of softening at the highest heat of the furnace; (*b*) a squatting point not below Cone 31 or 1690° Centigrade; (*c*) a high alumina content not below 30 per cent; (*d*) the greatest freedom from impurities; (*e*) a fine grained texture; and (*f*) a high degree of plasticity. These are the qualities most essential for glass house work. The figures given by the chemical analyses of good fire-clays would probably fall within the following limits—

Silica	49%	to	65%
Alumina	48%	,,	31%
Ferric Oxide	0·5%	,,	1·5%
Titanium Oxide	*nil*	,,	1·5%
Lime	*nil*	,,	0·5%
Magnesia	*nil*	,,	·2%
Total Potash and Soda	0·5%	,,	1·8%

Clays of higher silica content than 70 per cent would not be considered suitable as pot-clays owing to the ease with which glass attacks silicious clays. It is important that chemical analyses of fire-clays should be compared with results obtained from the analysis of fired or burnt samples, or they should be recalculated to allow of such comparison, so as to exclude the figures for the hygroscopic and chemically combined water of the clays.

The writer gives the following particulars of a fire-clay very suitable for glass house pot-making. It is plastic and highly refractory, and is now being considerably used by the trade. The clay is supplied by Mansfield Bros., Church Gresley. The figures are from a report made by Dr. J. W. Mellor, D.Sc., of the County Laboratory, Stoke-on-Trent, and are as follows—

Raw Fire-clay Dried at 109° Cent.

Silica	46·45	per cent
Titanic Oxide	2·65	,,
Alumina	35·32	,,
Ferric Oxide	1·31	,,
Manganese Oxide	—	
Magnesia	0·09	,,
Lime	0·41	,,
Potash	1·08	,,
Soda	·76	,,
Loss when calcined over 109° Cent.	12·14	,,

The melting point is given as equal to Seger Cone 33 or 1730° Centigrade.

The physical properties of fire-clays vary as well as their chemical properties. The analysis alone of a fire-clay is not always sufficient indication as to its ultimate behaviour when in use. Many physical tests have to be carried out before a clay can be proved satisfactory for a particular purpose, and much information can be gained by engaging the services of a specialist upon refractory materials to carry out petrographic, pyro-chemical, and physical tests, and report upon the suitability of the material for its specific purpose. Fire-clays should be plastic, and this plasticity should be developed to its utmost to increase the binding properties of the clay when used. To develop the plasticity, fire-clays should be weathered or exposed in thin layers to the action of atmospheric influences. The heat of the sun and the action of frosts and rain have a direct influence in breaking up the clay and developing its better properties. The use of new unweathered clay is the cause of much trouble to the glass manufacturer who makes his own pots and furnace goods, and on this account he should insist upon having his clays weathered for some time before use, so as to have them thoroughly matured. Before fire-clays are weathered or used for important work they should undergo a process of selection and cleansing. When they are first raised from the mines all foreign and inferior portions, carbonaceous matter, vegetation, iron pyrites, and stones are removed. The best and cleanest portions of the fire-clay are sorted out and removed to the weathering beds, where the lumps are broken down to small pieces about the size of an egg, and left to mature and season by weathering.

This fire-clay is then spread out in a layer about 2 ft. deep, and, after a period of exposure to the action of the weather, the heap is turned by men shovelling the clay from one side to the other. The clay, under the continued action of the wind, frost, and rain, disintegrates and slacks down until it is reduced to a mild, fine-grained mass, which condition shows it to be well seasoned and ready for use. Fire-clays vary in this respect : some clays season quickly in the course of a few months, others take years to develop their proper nature. The former may be classed as mild fire-clays, the latter as strong fire-clays.

After weathering, the clay is carted or conveyed to the clay-grinding plant, where it is stored under cover until it is dry enough to be ground on the clay-mill. Here the clay is fed into a revolving pan, and crushed under heavy iron runners, and, after passing through perforations in the bottom of the pan, it is elevated on to screens which sieve the clay to a requisite degree of fineness. It is then admixed with a large proportion of ground burnt fire-clay, and the mixture is tempered with water until it forms a plastic mass or dough, which is conveyed to the workshops where the furnace blocks or pots are to be made. These making and drying shops have false or double floors, under which steam or heated air is passed by means of pipes or flues below the floors, giving the steady and uniform heat which is necessary to dry the fire-clay goods as they are made. Heavy fire-clay goods should on no account be hurried in drying, lest trouble should occur through the goods cracking or warping.

In making the blocks for the furnaces the workman takes a portion of the prepared clay and tramps the plastic mass into a wooden frame, or mould, the shape and size of the block required, with due allowance made for shrinkage. The blocks are made on the warm floor, which is of cement or overlaid with fire-clay quarries. When the mould is filled the surplus clay is cut off and the wooden frame is lifted up, leaving the clay block on the floor. The empty mould is then cleaned and refilled. The blocks are left until they attain considerable stiffness from the evaporation of the water brought about by the heat of the room. They are then dressed and cut to the final shape desired, after which they are further dried until they become quite hard and white. When thoroughly dry the blocks are removed from the drying sheds to the kiln for burning.

In burning thick and heavy blocks much care and vigilance are required in expelling the chemically combined water present in the clay, and, as the temperature rises and approaches red heat, the rate of heating should be retarded to allow proper oxidation to take place throughout the structure of the fire-clay blocks, and to prevent black cores being formed. In all fire-clays, besides the mechanically admixed water used in preparing the clay to a plastic mass, which is mostly driven off whilst in the drying shed, there exists water in a chemically combined state. This combined water is not expelled below 250° Centigrade, and is tenaciously held by many varieties of mild fire-clays. Due care has to be exercised in dehydrating goods made from such clays; therefore, the man in charge of the burning regulates his fires, keeping the kiln at a moderate heat for some time to allow this chemically combined water to be properly and completely expelled. This dehydration stage in burning clay goods occurs between the temperatures of 300° and 650° Centigrade.

After the dehydration stage of burning is completed, the fireman raises the temperature within the kiln to a dull red heat, when the next stage in the process of burning begins. This is the oxidation period, during which any organic carbonaceous matter present in the clay is expelled. During this stage in burning, fire-clay goods require an extended time, so as to allow for the heated air to permeate and get to the interior portions of the blocks and oxidize the cores; otherwise the blocks are badly burnt.

After the oxidation stage is completed, the fireman raises the heat quickly until he obtains a high temperature, sufficient to eliminate and complete the shrinkage of the goods. When this heat is sufficient to complete the fire-shrinkage, the burning is finished and the kiln is allowed to cool down. The blocks, when cold, are then withdrawn and delivered to the furnace builder.

For the erection of the furnaces several grades of fire-clay blocks are used, according to the conditions and nature of the heat they have to resist. In the presence of reducing agents, fuel ash, or glass, fire-clay goods vary greatly as to their suitability. So the local conditions to which they are to be subjected whilst under heat should be first ascertained, and the mixtures for the blocks adapted accordingly. So many differences exist in the pyro-chemical and physical properties of clays that their misuse is often apt to occur if the conditions under which they are to be used are not properly understood and allowed for. A fire-clay may show a high degree of refractoriness under a fusion test, and yet be less suitable for a specific purpose than one of less refractoriness showing better physical properties and of more suitable chemical constitution. The size of grain in both the burnt clay and raw clay used in the mixtures for making glass house furnace blocks is of the greatest importance. In many cases it is necessary to grade the ground-burnt material used, so that the proportion of coarse grains to the fine flour can be regulated to suit requirements. The burnt clay used in making the furnace blocks should be hard and well burnt, so as to prevent any after-shrinkage of the goods when they are used in the furnace. Fire-clay goods for glass house furnaces should not be burnt at a lower temperature than Cone 12, and in the construction of gas-fired furnaces and tanks, burning the blocks at a higher temperature, Cone 14, would give much better results.

On the Continent the glass manufacturers usually grind and mix their own fire-clays, with the result that they know exactly what they are using in making their pots and furnace goods, and they are not then dependent upon outside firms to carry out their wishes. English glass manufacturers usually buy their clays ready mixed, and as often as not have perforce to take the mixtures offered by the clay firms. Fortunately, in Great Britain many of the firms who supply the refractory requirements of the glass trade are well advanced in applying technical knowledge to their trade. The suppliers of refractory materials have co-operated with the glass manufacturers in a splendid way in recent years. Thus the length of life of the refractories, and this power of standing up to the higher heats of modern furnaces, have been greatly increased. A considerable amount of research and experimental work in connection with furnace blocks and refractories has been undertaken recently by a number of investigators, among whom may be mentioned the veteran Dr. J. W. Mellor, D.Sc., Professor W. G. Fearnsides, M.A., F.R.S., W. J. Rees, B.Sc.Tech., F.I.C., and Major Guy V. Evers.

CHAPTER VIII

GLASS HOUSE FURNACES

THE pots within which the raw materials are melted are set within a strongly heated chamber called the glass furnace. The old circular type of English furnace usually contains six, ten, or twelve pots, and will be described first. The pots stand in a circle upon a form of hob called the "siege," which constitutes the floor of the furnace. In the centre of this chamber and below the level of the siege is the "eye" of the furnace through which the flames come from the furnace fire below. The burning fuel is contained in a circular or cylindrical-shaped fire-box, about 4 ft. deep and 5 ft. in diameter, and is supported by a number of strong iron bars across the bottom of the fire-box. Passing under the fire-box, and across the whole width of the glass furnace, there is an underground tunnel called the "cave," each end of which is exposed to the outside air, which is drawn in through the cave by the draught of the chimney cone above the fire. The caves are of sufficient height and width to allow the fireman, or "teaser," as he is called, to attend to the stirring of the furnace fires from time to time. Using a long hooked bar of iron, he rakes out the dead ashes and clinkers, as they are formed, and stirs the fire through the bars by prodding the fuel with a long poker. The coal is fed upon the furnace fire through a narrow mouth situated in the glass house leading into a chute which runs under the siege, from the glass house floor level towards the fire-box of the furnace. The fuel is pushed down this chute and falls into the fire-box, and is fed at intervals of half to three-quarters of an hour, according to the heat desired and the draught allowed.

Above the siege and over the pots is a covering called the crown of the furnace, which is supported by fire-brick pillars. This is built of the most refractory material possible to be obtained, as the hottest flames from the furnace fires beat against this crown and are deflected downwards upon the surrounding pots. The flames, continuing their course, pass between the pots into small openings or flues leading from the siege floor and passing upwards through the pillars which are situated between each pair of pots; they then escape from little chimneys leading into the outer dome or conical-shaped structure so familiar to outsiders. This outer truncated, cone-shaped structure constitutes the main chimney of the furnace. The furnace chamber containing the pots is constructed entirely within this cone. The fire-clay blocks are carefully shaped, neatly fitted, and cemented together with a mortar made of fine, plastic, raw ground fire-clay mixed to thin paste with water. The presence of any molten glass which escapes from a cracked pot, and the fluxing action of the fuel ashes, cause severe corrosion of the blocks forming the siege and fire-box, and these necessarily have to be made of extra thickness in order to extend the life of the furnace. When the furnace crown or siege becomes badly corroded, the furnace has to be put out for repair; so generally an auxiliary furnace is kept at hand, in order that it may be started and the workmen transferred from one furnace to the other whilst the repairs are being done.

The action of the glass upon the siege of the furnace is very active, and any leakage quickly destroys the fire-clay blocks, leaving fissures which gradually increase in size until the blocks are eaten right through. Consequently, every care is taken to preserve the pots from losing metal. If by chance any pot develops a crack through which the metal leaks into the furnace, the glass working is ceased at that particular pot, and every endeavour is made to ladle out what remains of the metal, and so prevent any more running on to the siege and causing further mischief. The metal is ladled out of the pot by means of thick, heavy, iron spoons, with which the hot metal is scooped out of the pot and dropped into a large cauldron containing water. This is very exhausting work, but there is worse trouble still if the metal is allowed to continue to run through the crack in the pot and over the siege into the eye of the furnace, for it then fluxes with the ashes of the fuel, causing them to form into a big mass of conglomerate, which, lying in the fire, interferes with the draught and combustion of the fuel within the furnace, and which, before the furnace can be got to work properly again, has to be cut away, piece by piece, through the firebars whilst hot, until it is all removed. At the sign of any glass running down into the fires and through the bars, the teaser gives the word that a pot is leaking in the furnace, and when the pot is isolated the work of ladling the hot metal out into water begins in earnest. A pot which has cracked and leaks is useless for any further work of melting glass, and at a convenient time it has to be withdrawn from the furnace and a new pot substituted. Glass-melting pots form a very expensive item in the glass manufacturer's costs; consequently, every care is taken to prevent the pots within the furnace from getting chilled by inadvertently allowing the fires to burn too low or allowing cold air to rush through the bars, through unskilful removal of clinkers and inattention to the furnace fires. Sometimes these furnaces are fitted with a Frisbie Feeder. This is a mechanical firing arrangement fitted underneath the furnace bars, by which the fuel is fed upwards into the furnace box, so that all smoke given off by the fuel baitings has to travel through the hot fuel above, and thereby is more completely consumed, giving better combustion than when the black fuel is thrown on the top of the hot bed of fuel. A mechanically operated piston pushes up small charges of fuel from within a cylindrical-shaped box, which works on a swivel backwards and forwards as the fuel is fed into it.

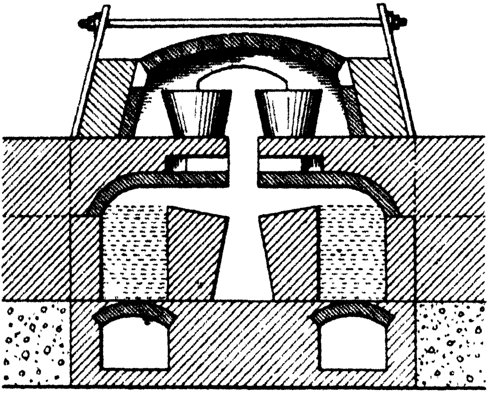


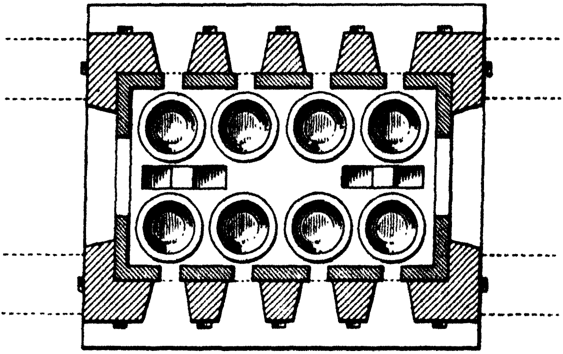
FIG. 3

SIEMENS SIEGBERT TYPE OF REGENERATIVE GLASS-MELTING FURNACE

In the old type of English furnace containing twelve pots, each 38 in. diameter and holding about 15 cwts. of metal, the furnace would be capable of melting 7 to 8 tons of glass a week, taking 40 tons of best fuel.

The more up-to-date glass-melting furnaces are constructed upon a much better principle than the coal-fired old English type of furnace just described. These are usually producer gas-fired and give more economy and greater convenience in every way.

In these better types of modern furnaces some form of regeneration or recuperation of the waste heat is usually adopted. These furnaces are much smaller and more compact; being gas-fired, they give much higher temperatures, more complete combustion of the fuel, greater ease in regulation, cleaner conditions, and far greater production than the older types of English furnaces. Considering the reasonable initial cost for which the latest types of these modern furnaces can be built, it appears incredible that so many of the old out-of-date English furnaces still remain in use in this country.



Sectional Plan.

FIG. 4

SIEMENS SIEGBERT TYPE OF REGENERATIVE GLASS-MELTING FURNACE

As examples of the types of regenerative and recuperative furnaces, a description will be given of the Siemens Siegbert Gas-fired Regenerative Furnace and the Hermansen Recuperative Furnace for glass-melting, which are extensively used on the Continent and are giving remarkably good results.

In the Siemens Siegbert type, the furnace may be a rectangular or an oval-shaped chamber, approximately 18 ft. by 9 ft., the crown of which is about 4 ft. 6 in. high. No outer cone-shaped dome exists, and the pots within the chamber are arranged much closer together and practically touching each other round the furnace. The furnace chamber is heated by a mixture of producer gas and heated air, the gas being generated in an independent gas producer situated outside the glass house and some little distance away from the furnace. At each end of the furnace, beneath the floor of the siege, are two blocks of regenerators. These are deep

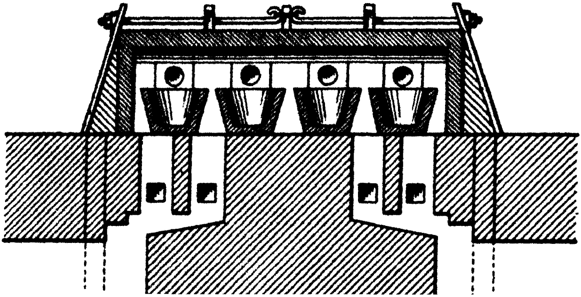


FIG. 5

SIEMENS SIEGBERT TYPE OF REGENERATIVE GLASS-MELTING FURNACE rectangular chambers containing an open lateral arrangement of fire-brick chequers, through which the air or products of combustion pass on their way to or from the furnace. Port-holes are situated directly above these regenerators which lead the gases through the floor or siege into the furnace chamber. The draught is induced by a tall stack, which draws the gas from the gas producers through a duplicate arrangement of flues to the port-holes at one end of the furnace, where it is mixed with the air which has been drawn and heated in its passage through the regenerator beneath. This gaseous mixture, whilst in combustion, is drawn across the furnace chamber to the other end of the furnace. The flames playing across the tops of the pots on each side pass down through the port-holes and regenerator at the opposite end. The hot gases or products of combustion, in passing through the lateral channels of this regenerator, leave behind their heat by the absorptive or conductive capacity of the fire-brick chequers through which the hot gases have passed on their way to the stack. The direction of the current is reversed at intervals of half an hour or less by using an arrangement of valves situated in the gas and air flues, so that the currents are made to travel in the contrary direction, the air necessary for combustion then being drawn through the hot block of regenerators which was previously heated by the exit gases. On its way through these lateral channels the air becomes intensely heated, and, when it is admixed with the coal gas at the porthole, this pre-heated air accelerates the combustion and calorific intensity of the gaseous mixture. So long as the high temperature is desired, the direction of the current is continually being reversed at half-hourly intervals or less by the manipulation of the valves as above described.

In practice, however, the regenerators are only used whilst the batch materials are being melted during the night, and by morning, when the metal is melted and "plain," the heat is brought back, or retarded, by using the gas from the gas producers and cool atmospheric air under natural draught, instead of the regenerated hot air. This cooler mixture, naturally not being so active in combustion, maintains just sufficient temperature for working the metal out during the day. Later in the day, when the pots are emptied and refilled with batch, the regenerators are re-connected, the founding proceeds again through the night, and the metal is again got ready for the workmen coming in next morning.

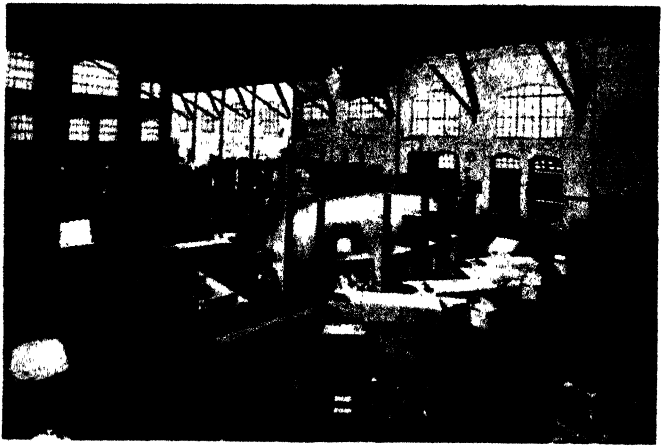


FIG. 6

A MODERN GLASS HOUSE

The Hermansen Continuous Recuperative Glass-melting Furnace in foreground (Twelve Covered Pot Type).

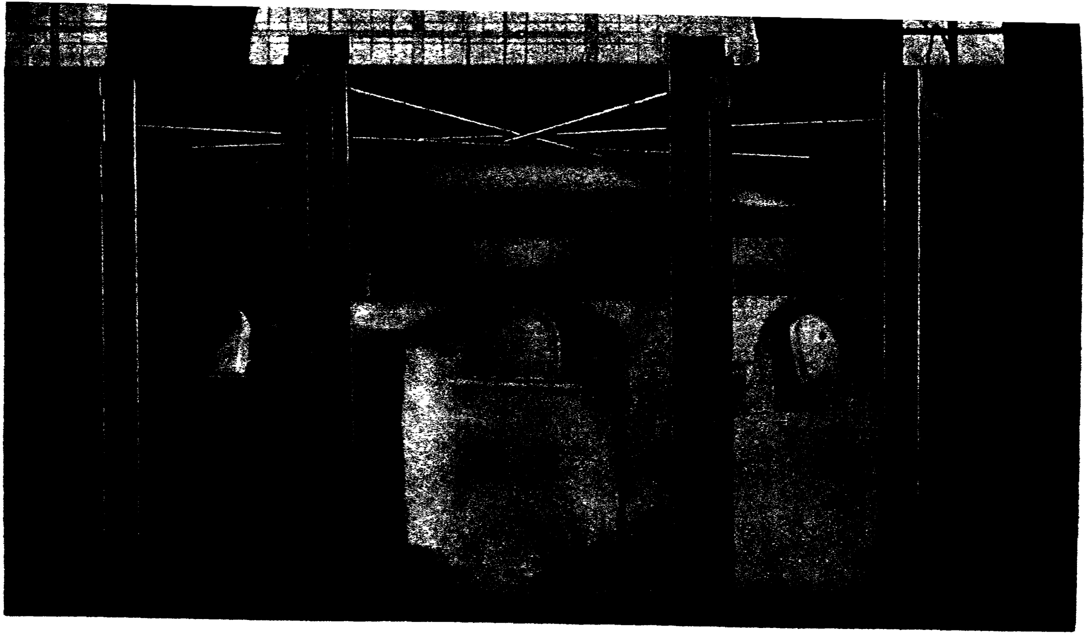
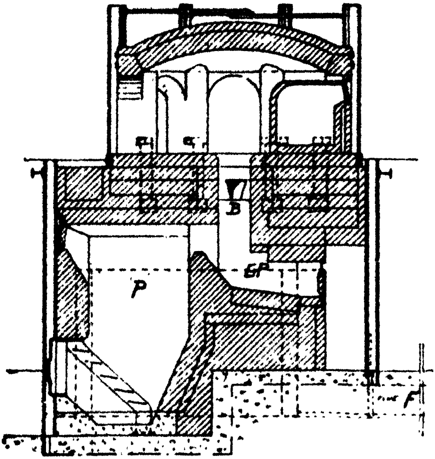


Fig. 7

HERMANSEN GLASS HOUSE FURNACE (EIGHT POT TYPE)

It will be seen that this method of melting and working out the metal does away with night work, the furnace man alone remaining in charge during the night. All firing is done outside the glass furnace room, which is well lighted, clean, and free from coal dust, totally different conditions from those existing in many English glass houses of to-day.



Sectional Elevation.

FIG. 8

HERMANSEN'S CONTINUOUS RECUPERATIVE GLASS-MELTING FURNACE

P. Gas Producer. *B*. Burner. *G.P*. Glass Pocket.

A Siemens Siegbert furnace taking ten open crucible pots, and filled each day, turns out 15 to 18 tons of metal a week. The crucibles are about 30 in. in diameter and have a capacity of 5½ cwts. of metal each. The amount of fuel consumed is about 18 tons a week. This type of furnace costs about £1,600 to £2,000 to build. In the writer's opinion, a disadvantage of this furnace is that, during the reversing of the direction of the fire gases, the greatest heat is suddenly brought to bear on the cooler pots, resulting in short life for the pots. The temperature of the incoming air is not so constant as with the recuperative type of furnace; however, with proper control, these defects may be obviated to some extent.

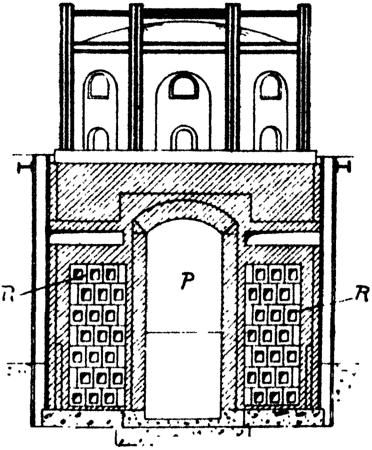


FIG. 9

HERMANSEN'S FURNACE

Cross Section through Gas Producer.

P. Gas Producer. *R*. Recuperators.

By the kindness of Messrs. Hermansen, the patentees, their Recuperative Glass-melting Furnace, eight pot type, is illustrated.

The Hermansen furnace, like the Siemens furnace, is producer gas-fired. The gas producer *P* is built within the body of the furnace, below the glass house floor. On each side of this gas producer the recuperators are situated. These are constructed by an arrangement of fire-clay tubes, designed to give two distinct continuous channels, the one horizontal and the other vertical. The vertical channels are connected with the atmosphere and supply the air necessary for combustion. The horizontal channels (*R*) are the flues through which the hot waste products of combustion are continually being drawn from the furnace by the stack. It will be evident that, the horizontal channels being intermediate to the vertical tubes, the waste heat is continually being absorbed by the air travelling inwards. In other words, the air is pre-heated by passing through flues which are surrounded by the hot waste gases. Therefore, in this type of furnace there is no necessity for reversing the currents to procure the necessary preheated air for combustion, and the regulation of the

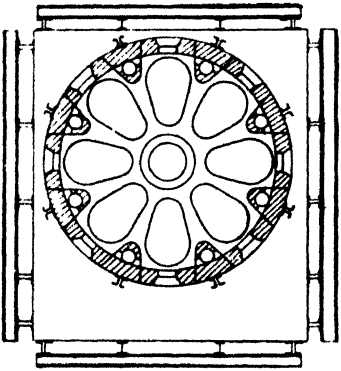


FIG. 10

PLAN OF HERMANSEN'S FURNACE

(Eight Pot Type.)

furnace heat becomes a simple matter of controlling the draught by means of the dampers provided in the main flue. In this type of furnace the glass is melted nightly; open or covered pots may be used, the capacity of which varies between 5 and 12 cwt., according to the class of glassware manufactured. The furnace is designed in four, six, and eight pot types, and several are now working in this country. These Hermansen furnaces are capable of producing 20 tons of metal, with a fuel consumption of 16 tons.

The Hermansen Continuous Recuperative Furnace is the most efficient furnace known to the writer. It is easier to control than the regenerative types. Being compact, it takes up little space and is easy to repair, and its life well surpasses that of other types. The initial outlay and cost of erection vary from £2,000 to £3,000. The combustion in this type of furnace is so perfect that it is used with open crucible pots for melting lead crystal glasses. On the Continent this furnace is in general use for all types of glass ware, and, considering the amount of glass it will melt, its efficiency is greater than that of the regenerative type.

Tank Furnaces. The use of tank furnaces in the glass industry is closely associated with modern mass production methods. It will be evident that where automatic machinery is employed the amount of metal contained in the crucibles of even the largest pot furnaces would be entirely inadequate. It thus came about that for the making of any kind of glass in bulk the whole furnace was given over to the melting operation, instead of just the crucibles within it.

The tank furnace consists essentially, as the name implies, of a great tank or reservoir of the molten glass. When first they were introduced tanks were used only for dark green bottles and other inferior types of ware.

They provided quantity without quality. Constant improvements have taken place, however, and almost any kind of glass can now be made from them. Most of the pressed table glass imported into this country from the Continent and America, prior to the imposition of tariffs, was made from tank metal, the colour and quality of which were uniformly admirable in its class. Tanks are replacing pot furnaces to a rapidly increasing extent, pot furnaces to-day being reserved more and more for such work as optical glass, heavy lead table ware, glasses in colour, or with other special properties which are only called for in small quantities, etc.

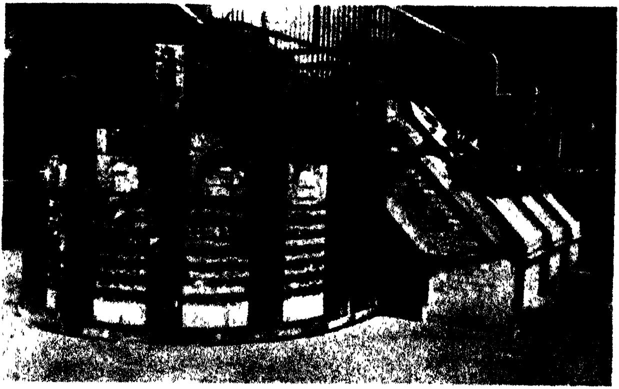
Tank furnaces are usually much longer than they are broad. The chemicals are fed on at one end and flow slowly down to the working end, the melting and refining taking place on the way. Thus one of the advantages the tank has over the pot furnace is that the working out and the founding processes can both proceed at the same time.

The batch is not introduced directly into the tank, as this would permit the entry of cold air, which would cause difficulty in regulating the furnace temperature. Accordingly, the chemicals are first fed into a separate chamber projecting from the furnace at the melting end and known as the "dog-house." When hot the batch is shovelled through apertures into the furnace proper.

Tanks are often divided into two zones by a bridge, which serves to keep back unmelted batch from the working end. Below the surface there are what are known as "dog-holes" in the bridge, which allow the passage of the molten glass.

There are two types of tank furnace commonly in use, the Regenerative and the Recuperative, both of which are gas-fired. Of these the former was the first to be introduced. The name in each case refers to the method of heat recovery used.

Regenerative Tanks. This system is similar in principle to that already described under pot-furnaces. In the "Harvey-Siemens" type two air regenerators, flanked by two gas regenerators, are placed below the centre of the furnace. In the case of the "Simon-Carves" type the regenerators are built on each side of the furnace instead of beneath it. By means of valve control the gas currents are caused to flow first from left to right, and are periodically reversed so as to flow from right to left.



Courtesy of Messrs. Stein & Atkinson, Ltd.

FIG. 11

OIL-FIRED REVERSING REGENERATIVE GLASS TANK FURNACE

View at refining end, showing working holes.
This tank is worked both by hand and by machine.

The disadvantages of the regenerative system are that the change-over results in a fall in the furnace temperature, and that ports and flues are somewhat complicated.

Recuperative Tanks. Tanks built on the recuperative system generally occupy less space because of the smaller number of flues, etc., needed, and are consequently cheaper to erect. The hot gases leaving the furnace pass through the recuperators on their way to the stack, and in so doing cross brick or tile passages of high thermal conductivity containing the gases entering the furnace, which derive additional heat in this way. The system is a continuous one, and the furnace temperature can therefore be kept constant.

A shortcoming of the recuperative system is that as the gases enter at a comparatively low temperature excessive soot may be deposited through dissociation of the carbon monoxide. In addition the elaborate blocks required to provide passage-ways in two directions at once make the structure of recuperators somewhat fragile, and leakage of gas from one tube to another is difficult to avoid.

Two of the best-known and most reliable types of recuperative tank furnaces for glass-melting are the "Hermansen-Teisen" and the "Stein & Atkinson."

CHAPTER IX

GLASS-MELTING POTS AND THEIR MANUFACTURE

GLASS house pots are large hollow vessels made of refractory fire-clay in which the glass manufacturer melts the materials of which his glass is composed, and which retain the molten metal whilst in a state of fusion for the workmen's use. In the case of the lead crystal glass, the materials, whilst being melted, require protection from the flames, smoke, and fuel ash present in some degree in any type of furnace chamber, which would otherwise reduce the lead present to a metallic state and spoil the glass; therefore, such glasses are melted in covered or hooded pots and thus protected from the direct action of the flames. Consideration has to be given to the extra amount of heat required from the furnace to find its way through the hood of the pot. For crown plate and chemical glassware, the metal is usually melted in open or uncovered pots. In this case the fusion is facilitated by allowing the heat of the furnace to come into direct contact with the materials within the pots.

Pots which are covered or hooded have an opening cut out in the front, in a position just above the level of the molten metal. Through this opening the workman gathers the hot metal. In the case of open pots, the crucible is set in a similar position within the furnace, but the working hole or mouth is built to form part of the construction of the furnace in front of the crucible.

Good pots are of the greatest importance to the glass manufacturer, and upon their life much of the success of glassmaking depends. They have necessarily to resist the corrosive action of the raw materials and molten glass within, and, at the same time, withstand the very intense heat of the furnace without giving way under the great weight of the glass within them. Should a pot of metal give way whilst in the furnace, the loss is considerable and very serious, for not only has the metal been wasted, but much of it has flooded the floor of the furnace and siege, and, finding its way into the fire-box, has attacked the furnace walls, fusing and melting with the fuel ash, checking the draught, and causing endless trouble.

Glass-house pots are very difficult and expensive to manufacture, and upon an average each pot has cost £10 by the time it is set within the furnace; therefore, every care is taken to extend their life by procuring the best possible materials for their manufacture.

Only the best selected pot-clays available are used, and every endeavour is made to keep them clean and free from foreign contamination. Only the best portions of the fire-clay seam are taken for this purpose, and a considerable amount of diligence is used and stringent precaution taken to procure the best qualities. As the clay is raised from the mine, clay pickers look over the lumps and select the best portions. A foreman of long experience is stationed at the head of the mine, and it is his duty to supervise the clay pickers and see that every care is exercised to guard against any unfortunate results which would naturally attend indiscriminate or indifferent selection. The best portions having been selected and placed aside, the lumps are scraped on the surface to remove any dirt, and broken into small pieces. They are again carefully examined on all sides and cleaned from foreign matter, such as pyrites or bluish parts. If this is carefully done, and the clays analysed and tested from time to time, a good pot-clay is obtained.

The clay for burning is treated in a similar way and dried. It is then burnt to a very high temperature and taken to the mill to be ground to the necessary fineness of grain. All pot-clays are well seasoned and weathered before use. They are first ground to a very fine flour and then mixed with ground burnt clay, or " chamotte." The proportion of raw clay to burnt varies with most manufacturers, but depends very much upon the plasticity or binding property of the raw pot-clay used. The burnt clay is preferable if ground to a size about 1 to 1½ mm., being sieved to take out any coarser particles. Some clays are more plastic than others, so the proportions in the pot-clay mixtures may vary from six parts of burnt clay to five of raw, down to one part of burnt clay to three of raw clay. The proportions are reckoned by volume, not by weight. The mixture is sieved into a trough and mixed with water to form a stiff paste, and removed into a large tank, where it is allowed to soak for some time. It is then well tempered by treading with the bare feet until the whole mass becomes plastic and tough. The clay mass is turned and trodden several times, in order thoroughly to consolidate the clay particles. Many efforts have been made to do this work mechanically, but without success. The fact remains, and experience has proved that, in the process of treading, the clay is more consolidated than by any mechanical method of preparation. The tempered and toughened clay is then allowed to sour and mature for a few weeks before use. It is then ready for the pot maker to begin the work of building the pots.

The room in which the pots are to be made is kept evenly warm by means of a series of hot water circulating pipes arranged around the outer walls. Usually a temperature of between 60 to 70° Fahr. is maintained.

Double doors are provided at the entrance, with a porch, so as to prevent sudden inrushes of cold air and prevent draughts in the pot-making room. All unauthorized persons are prohibited entrance, and only those who work therein are allowed free access. They are made responsible for keeping the place clean, as well as looking after the clay and taking care of the pots whilst they are being made.

The usual shape of a pot is of round section, 38 in. in diameter and 42 in. high, but many other shapes and sizes are used, according to the class of goods being manufactured. Thus, for colours, a very much smaller pot, less than one-third this size, is used, three of them, taking the position of one large pot, being set within one arch. For sheet and optical glass, a covered pot with a very large mouth or working opening is used.

In some instances, as in the Hermansen furnace, the pots are oval or egg-shaped. These are used on account of their larger capacity in relation to the space occupied in the furnace. Other pots have an interior division, which has a syphonic refining action upon the glass; such pots permit of continuous melting and working, instead of the intermittent process adopted when the regular or common shape is used. For plate glass, open crucible or bowl-shaped pots are used.

In regard to the manner in which the pots are made, and their subsequent treatment in annealing, the utmost care and control are necessary. In making the pots, the pot maker begins by making the pot bottom first, working the plastic clay paste into rolls about the size of a large sausage. He takes these rolls and applies them one after another in a circular form upon a round level board, the size of the bottom of the pot.

This board is supported on a low table. As he applies the rolls, he presses them together so as to exclude all air spaces between them, and continuously works the rolls on the top of each other in circles, until he gets a circular flat slab of clay in thickness about 4 in. and the width of the pot bottom. He then has the necessary thickness and size of the pot bottom formed as a clay slab, which is smoothed and levelled over the face with a knife or straight piece of wood. The slab of clay is then reversed upon another board, covered with a strong hurden cloth and a layer of ground burnt clay which prevent the clay from sticking to the board, and facilitate drying of the pots.

The first board is then removed, and the pot maker begins to build the sides or walls of the pot upon the circular clay slab by working the clay in rolls round the circumference of the slab to a thickness of 3 in., which gives the thickness of the pot walls. As he works and presses on each roll with his right hand, he supports the inside of the curve with his left hand, and presses roll after roll round the circumference of the slab of clay, building up the walls until they attain a height of about 6 in. The height of the walls is increased about 6 in. every other day or so; these time intervals allow each section built to stiffen a little before the next section is begun.

The workman passes from one pot bottom to another, building up the sections until the walls are raised to a height of about 30 in., when he places within each pot a clay ring about 18 in. in diameter, which he has previously made.[1] After placing these rings within the pots, the pot maker begins to form the hood or dome of the pot by working on the clay rolls, and at the same time drawing the sides inwards towards the middle, lessening the thickness of the walls and gradually diminishing the open space until it is covered and sealed in. Whilst the clay is still soft, the mouth or working opening is worked on and cut out of the dome, and the whole finished and smoothed by means of wooden tools.

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[1] These rings, floating on the metal, are used by the glass makers to keep the scum of the glass away from the middle portion from which he gathers.

The pots are now completed and are left to dry gradually at a moderate heat, which is increased a little at the end of a few months in order to dry them thoroughly. They are then removed from the boards and are ready for the furnace.

Crucible pots are made in a similar way, except that at the height of about 27 to 30 in. the pot maker finishes off the top edge of the walls and leaves it in that form to be dried.

Many efforts have been made to manufacture pots by other methods. One which has been tried with a fair amount of success is to cast the whole pot or portions thereof by using a plaster case mould and pouring in liquid clay slip. Another method which has been tried is to press the form by means of a hydraulic press and mould. Other mechanical contrivances have been used, but few of them have given such satisfactory results as the hand method.

MIXTURE FOR POT-CLAY

		By volume.
(Base)	Fine ground strong Fire-clay	5 parts
(Binder)	Fine ground mild Plastic Fire-clay	4 ,,
(Grog)	Chamotte	2 ,,
,,	Ground selected Potsherds	½ part

The fusion point of the mixture should not be less than Cone 32, or 1710° Centigrade.

Strong fire-clays are those coarser and harder grained, and are usually more silicious and less plastic than the mild fire-clays. Mild fire-clays are very fine-grained, plastic, and easily weathered clays. They act as the binder portion in fixing the burnt grog used in pot-clays.

The raw clays should be ground very fine and separately from the burnt clays. The ground burnt variety should be crushed from hard, well-burnt fire-clays, and should pass a sieve of ten meshes to the linear inch.

The mineralogical composition of the fire-clays for making pots is important. The presence of pyrites renders fire-clays unsuitable as pot-clays. Some indication as to the subsequent behaviour of a fire-clay can be obtained by submitting it to a petrographic examination and the usual pyro-chemical and physical tests carried out in testing refractory materials. In this country, Stourbridge pot-clays are chiefly used for pot-making, and so conservative are the majority of glass manufacturers that they will not use other clays, although, in the writer's opinion, many better clays exist in Great Britain, and have now been introduced and used successfully by some firms for pot-making.

Ground potsherds are selected pieces of old broken pots, cleaned from any adhering glass. These selected pieces are crushed and ground in a similar way to the burnt clay, and sieved to the same degree of fineness before use.

Plumbago glass house pots are sometimes used. These are made from mixtures of graphite, or plumbago, and raw fire-clay. They are very refractory and withstand the attack of very basic glasses, where such have to be manufactured.

Pot rings are made by taking a long roll of clay about 3 in. in thickness and shaping it round a circular frame. The two ends are joined and finished smoothly, the frame taken away, and the ring dried. A ring is placed in each pot.

Stoppers are the lids used to close the mouths of covered pots whilst the metal is being melted. These are made in plaster case moulds by pressing a bat of clay into the desired shape and releasing the outer case by turning the whole upside down upon a board and lifting off the mould. An indentation is made in the middle, forming a small hole. An iron rod can there be inserted, by which the stopper can be lifted away from the pot mouth whilst hot. Stoppers are burnt before use, and are made in various sizes to fit the mouths of different pots.

It is always advisable for the glass manufacturer to make his own pots and prepare his own clay, as he then knows exactly what he is using, and he is not dependent upon outside firms for his pots, as he has them ready at hand when needed. The conveyance of pots from one district to another by rail or road is always accompanied by considerable risk, as the vibrations given them in such journeys often cause mischief. As they are very heavy and fragile, their loading and unloading into the wagons are often attended with mishap. As often as not, latent strains are caused, which only develop when the pot is put in the furnace.

Annealing and Setting the Pots in the Furnace. The pots, when made and dried, being of raw clay, have to be carefully annealed before they can be introduced into the hot furnace. In doing this, the pots are removed from the drying rooms and placed within a small auxiliary furnace called a pot arch, which is constructed purposely to anneal them and get them hot before they are placed in the glassmaking furnace. The pots are moved by picking them up on long three-pronged iron trolleys, made purposely to lift and move them about. The pot is set within the pot arch, resting upon two or three rows of fire-brick, which allow the trolley to be removed and brought away, leaving the pot in a raised position in the pot arch. The doors of the pot arch are then closed and sealed with a stiff clay paste or mortar, and slow fires started, which gradually heat the pot, until at the end of a week it is got to a white heat, and the pot is ready to be removed and set within the furnace for melting the glass.

At a convenient time, arrangements are made for setting the pot. All other work about the glass house has to cease, as all hands are required to help in the strenuous and arduous work. The old pot in the furnace, which has done work for several months, has to be withdrawn from the furnace and the new pot from the pot arch has to take its place. We see gangs of men here and there. Some are pulling down the wall of the furnace in front of the old pot, making an opening in readiness to remove it. Another gang of men advance with long, heavy, strong iron crowbars, sharpened at the points, with which by heavy blows and levering they endeavour to loosen the old pot from the floor of the siege, to which it has become firmly cemented by the heat and any leakage of glass which may have taken place. Eventually, by their combined exertions, they succeed in loosening the pot, and then, levering it up, they place the low iron pot trolley under it and drag it out of the furnace, when it is taken away and thrown aside.

The old pot having been removed from the furnace, the glowing heat radiates more intensely than ever into the faces of the men at work, who endure it in relays whilst they work clearing away the old bricks and preparing the siege for the new setting. When this is done, a gang of men open the pot arch doors, and, placing the iron trolley under the new pot, convey it to the opening in the glass furnace from which the old pot has been removed. Facing the terrific heat, they struggle to push the new pot into its place in the furnace, with the aid of crowbars, and, working in relays, in turn face the heat till at last it is got into position. Naturally, everything has to be done in a hurry, so that the new pot may not be chilled before it is got into the furnace by being exposed too long to the outside air. The whole work proves very exhausting to the men, as there is little protection from the heat. After the pot is set in its place, the trolley is brought away and the wall of bricks rebuilt up in front of the pot to protect it, clay being daubed over the exterior of the brick wall to prevent any inrushes of air, which would cause the pot to crack by finding a way through the joints in the brickwork.

The furnace, during these operations, is worked to its full capacity, so as to allow for the very considerable loss of heat which takes place whilst the opening is being made and the pot removed.

The above is a description of the usual method of pot setting. In more modern and up-to-date works a travelling chain screen is used. This screen is like a curtain of loose chains, which is adjusted to hang in front of the open arch of the furnace and protects the workmen from the fierce heat. At the same time it permits the workmen to see and carry out the work of pot setting with greater ease and convenience. In using this screen arrangement whilst setting, the pot is pushed through the chain screen, which closes upon it after it has passed through. The workmen are thus enabled to get closer to their work by manipulating the crowbars through the screen, as the heat is not radiated fully upon them.

The newly set pot is allowed to stand empty in the furnace for a day or two to regain heat before it is filled with batch. It is first glazed on the inside by a workman taking a gathering of glass from another pot and plastering or covering the inside all round with the hot metal, which flows down and glazes the surface of the pot, giving it a certain amount of protection from the attack of the raw batch materials which are to be introduced later.

The founder, or glass melter, now takes charge of the pot, and he brings up the mixture of batch and cullet and shovels it into the empty pot until it is filled well above the mouth or level of the opening. The heat of the furnace melts the batch, and after several hours it becomes liquid and shrinks in volume so that probably only two-thirds of the height or capacity of the pot are occupied. The pot is then filled with more batch materials until it is full of molten metal up to the level of the mouth of the pot.

The furnace is kept going at its full heat until the founder, drawing a small portion of the glass on the end of an iron rod, examines it and finds that it is melted clear and free from seeds or bubbles of gas. When clear, the metal is " plain," and at this stage is in a very fluid state, too liquid to be easily gathered. It is, therefore, allowed to cool off by removing the stopper and leaving the mouth of the pot open until the glass becomes more viscid, or of a stiffer nature. The glass is then skimmed by dragging off any scum present on the surface, which is due to undecomposed salts that may have risen during the melting.

The metal is now ready for the glass blowers to begin work. Upon looking into the pot, the fire-clay ring will now be noticed floating on the surface of the glass. This ring keeps back from its interior any further scum that may arise whilst work is in progress. The glass blower always gathers from within this ring, where the metal is cleanest; and from time to time the metal within the ring is skimmed in order to keep that portion in the best condition. When the greater part of the metal within the pot has been gathered or worked out, the heat of the furnace is raised again, fresh batch materials are filled into the pot, and the process is repeated.

The time taken to melt the glass depends upon the heat of the furnace. A gas-fired furnace will melt the batches in eight hours.

CHAPTER X

LEHRS AND ANNEALING

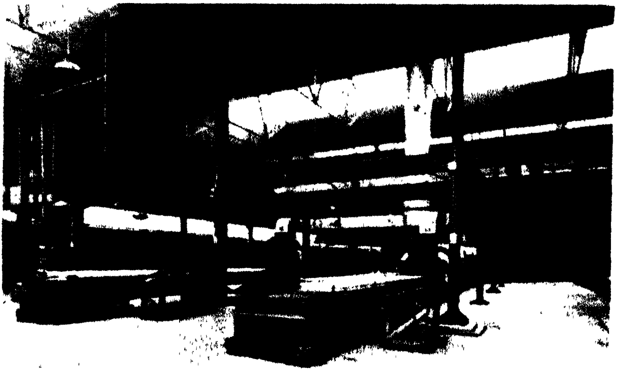
OWING to the peculiar structure of glass, and its liability to fly or collapse when exposed to sudden changes of temperature, a process of annealing becomes necessary in order to produce a more equal distribution of the tensions throughout the structure of the glass; otherwise, glassware of any thickness would be in such a state of tension as to be extremely liable to fracture when passing through any sudden change in the atmospheric temperature, especially in frosty weather. In this state it is useless or dangerous for general purposes. On this account most glasswares undergo a form of annealing at some time during the process of their manufacture. And in the case of certain goods, such as table glass, lamp glasses, optical glass, etc., special care and time are devoted to this process of annealing. Often in the case of improperly annealed glass, instances are known where its unhomogeneous structure has suddenly given way as the result of derangements set up by internal tension. Friction, or rough handling whilst cleaning, at the ordinary temperature of the atmosphere, is sufficient to cause a rupture. Therefore, annealing cannot be too carefully attended to.

A common early type of annealing lehr, which is still sometimes found in use, is that in which the glass is placed on a chain of iron pans or trays, which are hooked together. The pans travel down an arched tunnel, hot at the glass-house end but cool at the warehouse end. This primitive type of lehr is direct-fired. As the pans come out and are emptied at the cool end they are unhooked and carried round to the front of the lehr again for further use. The pans are mounted on wheels and run down the lehr on rails. The operation of the lehr is by hand labour.

In recent years the kind of lehr described above has been largely superseded by endless belt lehrs. In these the glass is carried on an endless metal belt, operated by a small electric motor. The belt itself is usually formed either of strong wire netting or of steel slats. The woven wire has the advantage that, being of light bulk, it becomes rapidly adjusted to the surrounding temperature. On the other hand, in the event of damage, single slats are simple to replace, whereas a continuous roll of wire fabric presents a more difficult problem.

In the modern lehr the conveyor is driven by a variable-speed motor. Light-blown glassware requires little annealing, and can therefore be passed down the lehr quickly. In contrast to this, large heavy glasses call for specially careful annealing, and are sent down slowly. The speed at which the lehr is working is regulated from time to time during the day in accordance with the type of glass that is being made.

One of the latest innovations in connection with annealing is that of the so-called "heatless" lehr, an indirect outcome of mass production. The system is an ingenious application of the fact that when a glass is first placed in the lehr it is still hot from the furnace. Granted that the number of glasses being dealt with is very large, it will be seen that a very considerable amount of heat becomes available in this way. If in addition the glasses are being passed through quickly this source of heat is being constantly renewed. It has accordingly been found that with the accurate modern control of the speed of transit through the lehr, and consequently of the annealing temperature, glasses such as bottles, which are being produced in bulk, can themselves provide all the heat necessary for perfect annealing. In a British Hartford-Fairmont lehr of this kind 22 tons of pint milk bottles were passed through in 24 hours. The works concerned stated that this was continued for a period of ten days, during which no fuel whatever was used, the heat in the bottles being relied on solely to accomplish the annealing.



Courtesy of The British Hartford-Fairmont Syndicate, Ltd.

FIG. 12

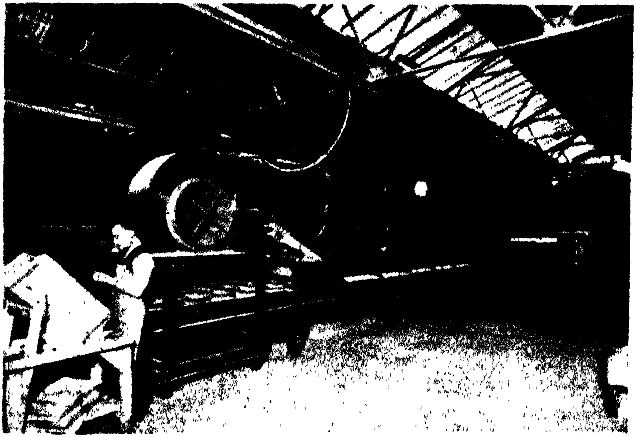
THE HARTFORD LEHR

With recent scientific control has come a great saving in the period of time required for annealing. In the old hand-operated lehr prior to the war the time taken for annealing varied from three to ten days. At the present day the electrically-driven endless belt lehr will anneal glass of a miscellaneous nature passing through under ordinary working conditions in between four and five hours. In case of special necessity this period could probably be reduced to as little as two hours. Lehrs dealing with bottles or other bulk products can accomplish their work in from one to one-and-a-half hours. Instances are on record of heatless lehrs annealing bottles in under an hour. The progress made since the war in the technique of annealing is therefore very remarkable.

Many physical changes take place in the glass passing through the lehr. One remarkable effect is the slight change in colour which occurs in glass decolorized with manganese. It is noticed that the glass becomes a greener tint in passing through the lehr when the decolorization is just on the margin of efficiency.

The state in which the structure of glass exists when quickly cooled and the action of annealing might be explained. When glass is quickly cooled, being a bad conductor of heat, insufficient time is allowed for the middle or interior portions of the glasswares to settle down and assume their normal state of solidification. The outer portion, or skin, will first cool and contract, with an enormous strain upon the hot interior. This difference in the state of tension between the outer and interior surfaces gives a want of uniformity, and stresses of tension and thrust are developed, which cause the whole to collapse with the slightest external scratch or heat change. In annealing, this strained or forced condition in the structure of the glass is relieved by subjecting the glass to a pre-heating, and gradually diminishing the temperature, allowing a sufficient time for the different layers mutually to adjust themselves to their comparative normal positions, and thus relieve the strains within the mass. Much depends upon the pre-heating temperature and the rate at which the diminution of the temperature takes place. If these are properly provided for, the best results are obtained in the stability of the resulting glass. The presence of any stress can be determined by using a polariscope.

The average British glass manufacturer has good knowledge of the value of a polariscope, or strain viewer, in ascertaining the physical state of his glassware, and now he has adopted its use there has been much improvement in his annealing methods. Little faultily annealed glass is being turned out, for this simple instrument detects badly annealed glass at once by the aid of crossed nicols and a selenite plate.



Courtesy of Messrs. Stein & Atkinson, Ltd.

FIG. 13

THE CHARLTON LEHR

On the left may be noticed the inspection of the glassware in a strain viewer.

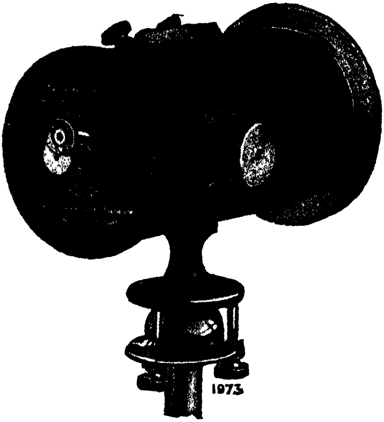
Owing to the unequal densities of the various silicates present in the heavy lead and barium glasses, they are more subject to striation and require more careful annealing than the soda-lime glasses, in which the silicates present are of more equal density. However, much depends upon the proper founding and melting of such glasses. The use of a larger proportion of cullet assists in breaking up striation. The presence of striae or cords in glass disqualifies it for most purposes, as it is usually found that, apart from their defective appearance, they tend to produce stresses within the glass.

Transparency, brilliancy, stability, and homogeneity are important factors in producing perfect glassware, and the proper development of these distinguishing properties requires considerable skill on the part of the glass manufacturer, alike from technical, physical, and practical standpoints.

CHAPTER XI

PYROMETRY

THE manufacture of glass depends on founding at high temperatures, commonly up to 1,400° C. For long the regulation of the furnace heat was left solely to the glass-house foremen, who had nothing to guide them beyond their own visual experience. In recent years, however, pyrometers have become the normal thing in connection with almost all furnaces, small as well as large, and also in the case of lehrs.

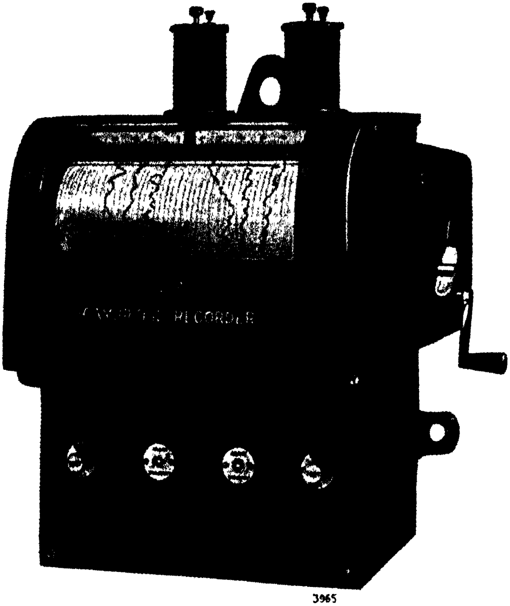


Courtesy of Cambridge Instrument Co., Ltd.

FIG. 14

FÉRY OPTICAL PYROMETER

Where automatic machines are in use it is specially important that there should be very close control of the furnace temperature. The glass supplied to the machine must always be of the same viscosity, or, at most, any variation must be within very narrow limits. If the temperature is allowed to rise or fall to the extent of only say 50° C. most glasses will become too fluid or too stiff to be worked mechanically.



Courtesy of Cambridge Instrument Co., Ltd.

FIG. 15

CAMBRIDGE RECORDING PYROMETER

This provides the means for recording the heat of three pairs of furnaces and lehrs simultaneously.

Pyrometer control of lehr temperatures is also essential, for the removal of strains and stresses from the glass, and the consequent saving of breakage, is largely a matter of the suitable grading of heat. Excessive heat, besides wasting fuel, can easily cause the glasses to become partly remelted and deformed while in the lehr. Incomplete annealing as regards the removal of strain is, on the other hand, usually the result of a cold lehr. From every point of view, therefore, lehrs require pyrometers just as much as furnaces if the best results are to be obtained.

There are a number of quite different types of pyrometers in common use. A very convenient instrument for occasional purposes, i.e. for the checking of furnace temperatures by the works manager, or for use during pot-setting, etc., is the Cambridge Optical Pyrometer. This is portable and has a range from 900° to 2,000° Centigrade. The cost is about £37. The Foster Fixed Focus Pyrometer serves a similar purpose, its standard range being from 500° to 1,800° Centigrade.

As a rule glass-melting furnaces are equipped with pyrometers of the recording type. Of these the best known in this country are the Cambridge Recording Pyrometer and the Foster Automatic Recorder. The system is that a galvanometer pointer or boom, actuated electrically or by clockwork, is intermittently brought in contact with a chart mounted on a rotating drum. By operating through an inked thread or ribbon the pointer records the temperature on the chart. The chart is replaced every 24 hours and the range of the instrument is from 700° to 1,400° Centigrade. The cost complete with all accessories is about £100.

Recording pyrometers are most frequently of the Thermo-electric type. Portable pyrometers are usually of the Electrical Resistance type. For specially high temperatures the Radiation type is sometimes used.

CHAPTER XII

THE MANIPULATION OF GLASS

THE tools used by the glass blowers are few and simple. The greater part of the crude form is produced by blowing out the hot glass into a spherical or pear-shaped bulb and regulating the size and thickness by gathering more or less material. The tools are mainly employed in finishing and shaping this bulb into the desired form, such as shearing, forming the neck spout, crimpling, and sticking on the handles to the various shapes made.

According to the type of the goods manufactured, different manipulative methods in forming the articles are adopted in various works.

The best English table glassware is mostly hand-made blown ware, generally entirely executed by the handicraft of the workman without the aid of moulds to form any part of the articles, and a considerable amount of skill and practice are necessary before the workman is competent enough to shape a number of articles exactly to the form of his model. It is astonishing to notice the skill and precision with which a workman produces wine glasses one after another, so uniform that one cannot trace any dissimilarity between them.

A second class, or cheaper form, of tableware is made by blowing the sphere or bulb of hot glass within a mould, to give some part, or the whole form, of the desired article. If only a portion of the intended shape is thus formed by the mould, it is afterwards finished by hand with tools. This is the general Continental method of working, and has only been partially adopted by this country for making tableware. Where a number of articles of one shape have to be produced, this is by far the most economical method. Glass tumblers, honey pots, and rose bowls illustrate this class of ware.

Another class of tableware produced by a method of pressing the form is known as "Pressed glassware." The hot metal is gathered from the pot, and a portion cut off and allowed to fall into an iron mould fixed within a lever press, which carries a plunger fitting within the mould formed to shape the interior and exterior, with the thickness of the glass as the intermediate space between them. As the hot glass is introduced, the workman brings down the lever arm and the plunger presses the hot metal to shape. The plunger is then released and the mould reversed; is turned out the pressed form of glass, and then carried away to be fire-polished or further manipulated with tools before it goes to the lehr. The case or mould portion is made in two halves, to facilitate the removal of the hot glass after being pressed. Pressed glass tableware can be recognized by the presence of seams, showing these divisions of the mould. Many exquisite designs imitating cut glass tableware are executed in pressed glassware. The moulds are a very expensive item, as there is much tool work in cutting the patterns and refacing them after prolonged use. In making pressed goods, an oily, carbonaceous liquid is used to give the moulds some protection and prevent the oxidation of the iron. This liquid is from time to time applied, as the work of pressing proceeds, by mopping the interior of the mould with a mop dipped in the preparation.

The Glass Blower's Tools. The glass maker's chief tool is the blow-iron. This is a tube of iron ½ to 1¼ in. wide and about 4 to 5 ft. long, one end of which is shaped or drawn in so as to be convenient for holding to the lips, and the other end is slightly thickened into a pear-shaped form, on which the hot metal is gathered.

In making crystal tableware the workman manipulates the glass he has gathered on this blow-iron by rotating it on a marver. This is a heavy slab of iron with a polished face about 1 ft. by 1 ft. 6 in., and 1 in. thick, supported on a low table. Sometimes this marver may be a block of wood with hollows of definite forms, in which the workman rotates the hot glass he has gathered to regulate the form and thickness of the metal to suit his work before beginning to blow it out into a hollow bulb.

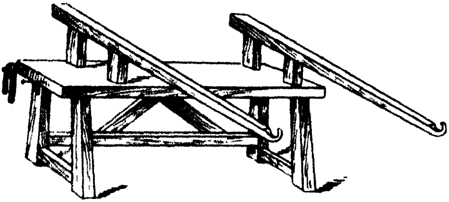


FIG. 16

GLASS WORKER'S CHAIR

The pontil is a solid rod of iron of similar length and thickness to the blow-iron. By gathering a little wad of hot glass on the pontil and sticking it against the end of the bulb attached to the blow-iron, the workman can detach the bulb from the blow-iron and hold it by the pontil to which it has been transferred, and which enables him to work on the other end or opening in the bulb which is exposed in detaching it from the blow-iron.

After re-heating the glass, he may shear it with his scissors or shears, open it out with his pucellas, crimple it with his tongs, measure and caliper it, or shape it to a template.

Whilst he is doing such operations he sits in a glass worker's chair. This chair has two long extending arms, which are slightly inclined, and along which he rolls his blow-iron or pontil, with the glass article attached, working upon the rotating form, turning the iron with one hand, whilst he uses his tools with the other hand, to shape or cut the glass to its requisite form whilst it is hot, soft, and malleable.

The shears are like an ordinary pair of scissors, and are used for cutting the hot glass, or shearing off the tops of bowls and wines to their proper height.

The pucellas is a steel, spring-handled tool in the form of tongs, which the workman uses to widen, extend, or reduce the open forms of glass by bringing pressure upon the grips of the tool whilst applying it to the hot glass.

The glass maker also uses another form of spring tool in taking hold of hot glass or pinching hot glass to form. These are the tongs.

The battledore, or pallette, is a flat board of wood with a handle, used for flattening and truing the bottoms of jugs or decanters, etc.

The chest knife is a flat bar of iron, usually an old file, used for knocking off the waste glass remaining on the blow-irons and pontils after use. A chest or iron box is kept for collecting such waste glass for further use. A pair of compasses, calipers, and a foot rule complete the glass maker's outfit of tools.

Making a Wine-glass. The manipulations in the manufacture of a wine-glass will now be described. A common mule wine-glass is formed from three distinct pieces of glass: (*a*) the bowl; (*b*) the leg; (*c*) the foot.

A wine "shop," or "chair," consists of three men—a "workman," whose main work consists of finishing the wine-glass; a "servitor," who forms or shapes the bulb; a "footmaker," who gathers and marvers the glass—and a boy who carries away and cleans the blow-irons.

The footmaker of the "chair" gathers on the end of a blowing-iron sufficient glass to form a bowl. This is then shaped on a marver until the required shape is obtained. The footmaker then blows this out to a hollow bulb similar in size to the pattern to which he is working. When the bulb leaves the footmaker it is the shape of the bowl of the wine-glass.

This is then handed over to the servitor, who drops a small piece of hot glass on to the end of the bulb, and heats the whole by holding it in the furnace. This serves to make the joint of the two pieces perfect. The servitor next proceeds to draw out the leg from the small piece of glass at the end of the bulb, leaving a button of glass at the end of the leg. The servitor then dips the end of the leg into the molten glass within the pot and gathers on sufficient glass to form a foot. He spreads this portion of the glass out to the required shape and size with a pair of wooden clappers, with which he squeezes the hot glass to form the foot.

The servitor has now done his part of the work, and the glass is handed to the workman. It is then cracked off, and the foot caught by a spring clip arrangement attached to a pontil, called a "gadget." The workman now re-heats or melts the top edge of the glass by holding it within the furnace, and when it is hot he cuts off the surplus glass with a pair of shears. A line is chalked on at the correct distance from the foot, and guides the workman in cutting the glass to the proper height. He then melts the top again and opens it out with his spring tool to the required shape, after which the glass is taken to the annealing lehr by the boy, to be annealed.

Other forms of wine-glasses are made, and various methods are adopted, according to the district and class of workmen.

For instance, the method of making the above common mule wine-glass varies in different districts. Instead of gathering the metal for the foot upon the leg of the glass, the workman may drop a piece of hot glass, which has been gathered by the servitor, on to the button at the end of the leg, and by means of a pair of wooden clappers spread the hot glass to form the foot.

In another method of making a wine-glass, the stem or leg is drawn out from the body of the bulb by pinching down a knob at the end of the glass. The servitor draws the leg out of this knob and knocks off the extreme end. Meanwhile, the footmaker has been preparing a foot, gathering a small portion of metal on a blow-iron and blowing it out and shaping it into a double globule. The end globule forms the foot and the second merely acts as a support. The footmaker takes these globules, and the servitor sticks them on to the drawn stem of the wine whilst it is hot; the blow-iron holding the globules is knocked away, leaving them adhering to the leg of the wine-glass. The footmaker then knocks off the second globule at the line between the two and, re-heating the bulb at the foot of the glass, opens and widens out the edges. The glass then goes to the workman to be finished in the same way as the common mule wine-glass.

Many articles of glassware are formed with the aid of moulds. Take as an illustration the manufacture of tumblers and honey pots. A quantity of glass is gathered on the blow-iron, marvered, and blown out into an elongated bulb, which is introduced into a mould divided in two halves, which open or shut by hinges, a handle being fixed on each half to facilitate the operation. The interior of the mould is made to the shape of the article, and as the bulb of hot glass is introduced the mould is shut; the workman blows down his blow-iron and extends the glass until it expands and fills the space within the mould, giving the complete form of the article with a surplus of metal just where the blow-iron is attached to the glass at the top. The top is then cut off and finished, either by the workman re-heating the article by attaching the bottom to a pontil and shearing off the top edge, or the glass is annealed in its unfinished state and the top surplus portion cut off by an automatic machine specially constructed for cracking off such goods.

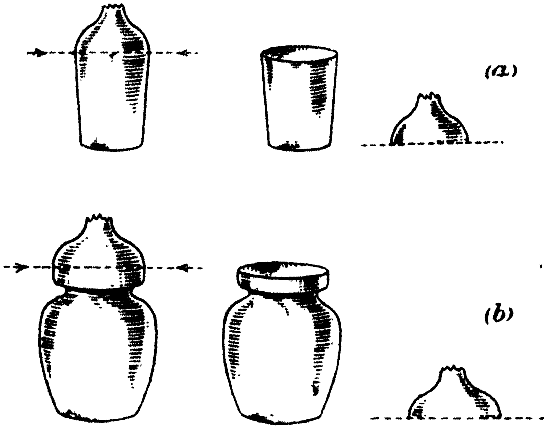


FIG. 17

GLASSWARE BLOWN IN MOULDS SHOWING PORTIONS CRACKED OFF

(*a*) Tumbler. (*b*) Honey Pot

Such machines consist of a set of revolving tables upon which the glass articles are centred, and each in turn revolves in front of a thin, pointed, hot jet of gas flame, which impinges on the glass at the height at which the glass is to be cracked off. After one or two revolutions in front of this hot pencil of flame, it is removed, and, by applying a cold steel point so adjusted as to touch the part where the jet has heated the glass, a chill is imparted which causes the upper portion of the glass to crack away in a clear, sharp line round the glass. This top portion of surplus glass is thrown aside and returned to the furnace for re-melting as cullet.

The tumbler or honey pot is then conveyed to another machine which fire-polishes the edges to a smooth finish.

This machine consists of a circular revolving frame carrying small supports, which themselves rotate on their own centres. Upon each support an article is placed to be fire-polished ; the frame carries the articles round, and they travel into another section of the machine, passing under a hooded chamber, which is heated by a fierce jet of flame. The jet of flame, which is localized on to the top edges of the tumblers or other goods passing through the hood, gives just sufficient heat to melt and round off the sharp edges of the glassware where they have been cracked off by the previous machines.

By using these machines in this way labour is considerably economized, and as many as 500 or more articles an hour can be cracked off and fire-polished with unskilled labour. The machines are extensively adopted in the manufacture of electric light bulbs, shades, lamp chimneys, and tumblers.

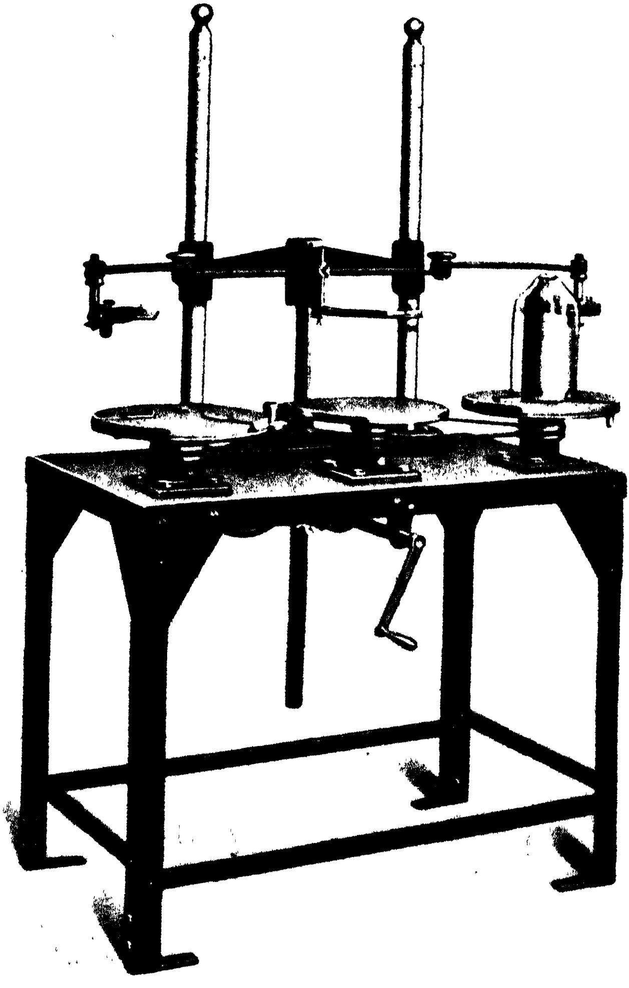
Moulds are usually opened, shut, and dipped by boys, but in up-to-date glass works an automatic machine, called a " Mechanical Boy," is used. With this machine, the mould is operated at the desire of the workman and not at the desire of the boy. The output is considerably expedited by the use of these automatic devices for opening and shutting the moulds.

It is obvious that whatever the shape of the mould, or whatever the design within the case, the glass takes the impression and retains it in after-working. In this way, square sections, fluted indentations, or raised bosses can be formed with facility and regularity.

The Glass Workers' Union consider that the introduction of machinery deprives men of their independence and right to work, but as yet the glass blowers have been always fully occupied with useful work about the factories in which such machines have been introduced, so it cannot be said that they have been forced to be idle.

The advantage possessed by these automatic machines in their larger output at so much less cost compared with hand labour is the great factor in inducing their adoption; and in these days of progress and competition such machines enable the glass manufacturers to cope with the increasing demand and go far towards bringing a factory up to date and making it well equipped.

Manufacturers should certainly turn their attention to these mechanical methods, as their use is quite general on the Continent and in America. By their use the metal can be worked out of the pots or tanks much more quickly, increasing considerably the turnout or capacity of the furnace against the fuel consumption. Much of the glassware imported into this country is composed of such articles as have been manipulated by machines, and, unless a similar method of manufacturing them is adopted here, we cannot hope to compete with other countries in supplying our own needs. In the writer's opinion, it is mainly due to the



By permission of *Melin & Co.*

FIG. 18

VERTICAL CRACKING-OFF MACHINE

adoption of machinery for producing glassware that the Continental people have been enabled to undersell us in our own market, and English manufacturers could produce at a much cheaper rate if they would only adopt similar methods of manufacture to those used abroad.

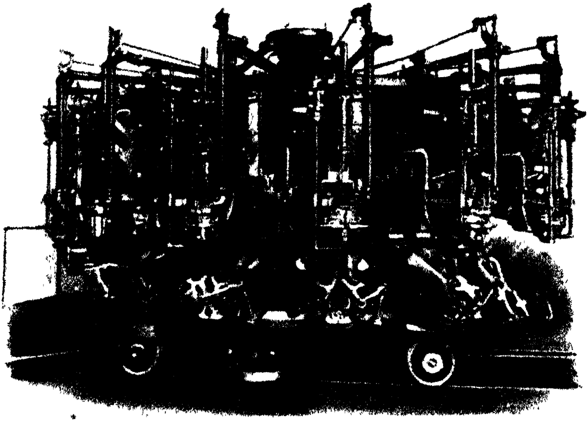
Lighting Ware. At the present day the making of illuminating glassware may be regarded as forming a halfway stage between hand and mechanical production. We can therefore observe in it some of the elements upon which more advanced processes have been based. Most lighting globes are blown in moulds by hand. To form any hollow glass vessel a bulb of glass must be blown. When the best table glass is being made it is tooled and fashioned by a skilled workman, and the outward shape depends upon his dexterity. But with lighting ware, instead of the laborious hand tooling, the same original ball of glass is blown out to its final shape in a mould. Bottles were also made in this manner until not very many years ago, but the great numbers in which they were required provided an incentive for further experiment in their case which was absent in that of illuminating globes, and they have now passed into a different class.

CHAPTER XIII

BOTTLES

Every year millions of bottles are used in this country, and their manufacture forms quite an important industry in itself. The largest producers of bottles in Great Britain are a combine of Lancashire origin, although since the war they have laid down a vast modern plant near London. The amalgamation was formed in 1912, with two old-established St. Helens manufacturers as the prime movers, to acquire the European rights of an automatic bottle machine invented in the United States by Michael J. Owens. In that year Owens came to Manchester and built a complete model glassworks in Trafford Park to demonstrate the capabilities of his machine.

Suction Machines. The Owens was the first fully automatic bottle-making machine to be an entire commercial success. An improved machine on the same principle has recently been patented in England by Redfern. The Owens is of the suction type, and consists of as many as fifteen arms revolving round a central shaft. Each arm is in effect a self-contained bottle-forming machine, complete with parison and finishing moulds. Every unit in turn dips to the surface of the molten glass, and by compressed air suction draws up into the parison mould sufficient of the glass to make the size of bottle required. This gathering of metal is eventually passed on to the finishing mould, where it is blown out to its final shape. Within certain narrow limits each arm can be used to turn out a slightly different bottle, but it is found in practice that the Owens type of machine, being somewhat large and cumbersome, is most suited to working on orders of extremely large size for exactly the same kind of bottle. It is not adaptable, and in recent years the preference of the trade has been moving in favour of the smaller and more convenient flow type of machine. As an example of the advance represented by the introduction of the fully automatic suction type of machine in bottle-making it may be mentioned that in the case of carboys an Owens carboy machine can make 7,500 to 8,000 five-gallon bottles in a day, whereas in the old hand-blown times a skilled glass-blower could at the utmost produce only 200 of this kind of bottle in the same working period.



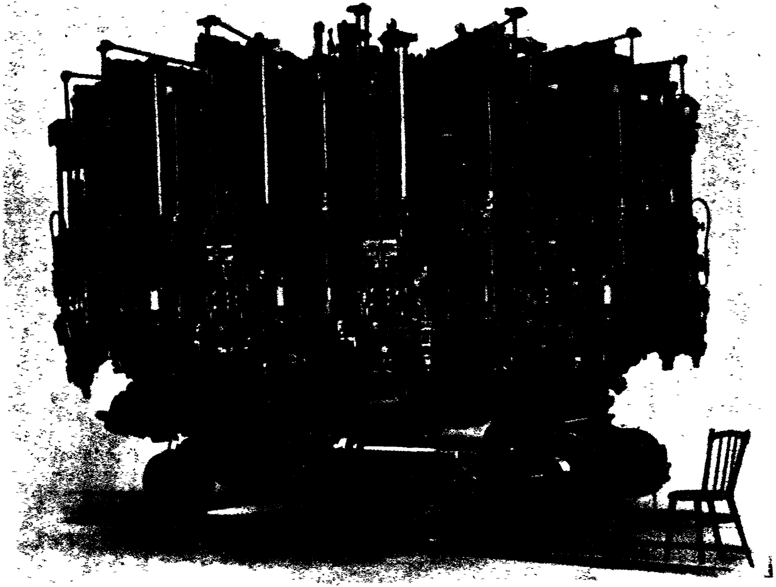
Courtesy of Owens-Illinois Glass Co.

FIG. 19

OWENS BOTTLE-MAKING MACHINE

The Owens machine is of the suction type, and was one of the first entirely automatic machines to be introduced in the glass industry.

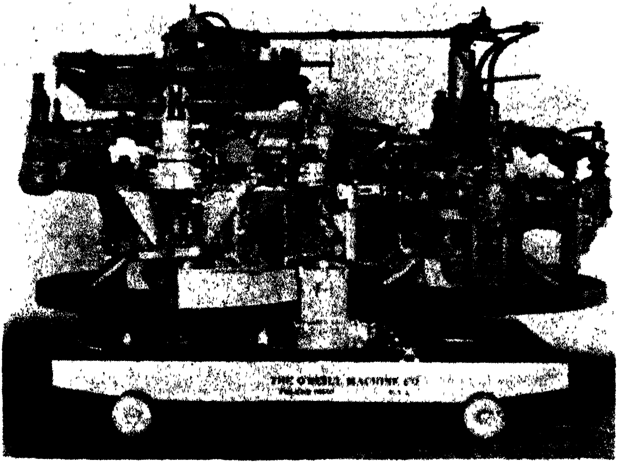
Flow Machines. The flow machines, of which perhaps



Courtesy of Messrs. John Walker & Sons, Ltd.

FIG. 20

"REDFERN" BRITISH BOTTLE-MAKING MACHINE (SUCTION TYPE) the best known is the American O'Neill, are not in themselves entirely automatic, and therefore work in conjunction with feeding devices, the most popular of which are the Rankin, Hartford-Empire and McNish. The bottle-making machine proper consists of two circular turn-tables, each of which carries six or eight moulds and rotates round a strongly built central column. It synchronizes with the cutting-off shears and plunger of the feeder. A plunger regulates the flow of glass being delivered by the feeder, and, with the shears, cuts it off into gobs of a proper size and shape for the work in hand. The gob of glass drops into a parison mould, which is in an inverted position, and has the neck ring and plug at the bottom. As soon as the mould is closed a valve opens automatically and compressed air enters, forcing



Courtesy of The O'Neill Machine Co.

FIG. 21

NO. 94 O'NEILL VACUUM MACHINE

the glass into the neck ring and round the plug at the bottom. The object of the plug is to pierce the lump of glass, and thus to provide an opening for the air to enter subsequently when the bottle is blown. When the table rotates to the next position the plug is withdrawn, and air is injected from below, blowing the glass to the shape of the parison mould. While the table moves round a further stage the parison mould revolves, so that when it is nearest the second or blow table it is no longer inverted but neck upwards. The bottle "blank," as it is called, moves across from the parison to the corresponding blow mould suspended by the neck ring. Here, as the second table revolves, it is blown to its final shape.

It will be realized that between each operation, or transfer of the glass, the revolving of the machine must stop for a moment while the transfer takes place. Robust construction of the machines is consequently necessary to withstand the mechanical strains brought about by the constant stopping and starting.

CHAPTER XIV

CROWN AND SHEET GLASS

THE first glass windows were probably made on what is called the crown glass system. The process consists of blowing a gathering of molten glass into a hollow spherical shape on the end of a blow-iron. To the opposite side of the sphere a pontil or solid iron rod is then attached by means of a nodule of the molten metal. The original blow-iron is now broken free, leaving an opening in the globe. By rotating the glass rapidly while still in a semi-molten state it opens out into the form of a flat disc, adhering to the pontil by the boss in the centre. When the pontil itself is detached a bull's-eye is left. Crown glass has two characteristics, the small size of sheet that can be made by this method and the unavoidable presence of the boss or bull's-eye in the centre.

Hand Cylinder. The next method of making window glass to be introduced was the hand cylinder process. In this the gatherer blows the glass into the form of a cylinder on a heavy blow-iron about five feet long. The gathering of glass for this purpose will weigh from 20 lb. to 40 lb. according to the size of cylinder being made. The cylinders vary from 12 in. to 20 in. in diameter and from 50 in. to 70 in. in length. After the cylinder has been blown the ends are removed and it is slit down its length. Re-heating in a flattening oven then causes it to fall into a flat sheet. This method is rarely employed at the present day, but the machine system that has replaced it resembles it closely in principle, though the operations have been greatly modified in a number of ways. In the march of progress the hand gatherer has been eliminated and his place taken by machines.

Machine Cylinder. In the machine cylinder process, by substituting compressed air for the human breath it has become possible to blow very much larger cylinders than formerly. On account of their increased sizes these in turn require special apparatus to handle them.

Courtesy of The Institution of Mechanical Engineers

FIG. 22

MACHINE CYLINDER SHEET GLASS PROCESS

First stage, showing the molten metal being poured into the crucible on the right of the picture, and the beginning of the draw on the left.

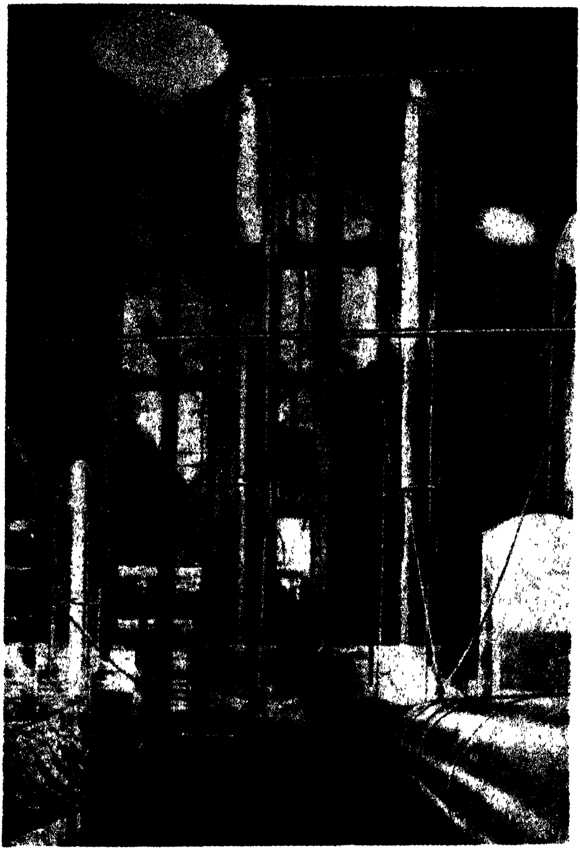
The most recent advances in this system bring it into some relationship with other sheet glass processes to be described later. The metal is taken from the furnace in enormous ladles and filled into open crucibles on the glasshouse floor. Above each of a row of such crucibles is drawing mechanism by means of which a metal pipe or "bait," representing the old blow-iron, is lowered into the crucible. The glass adheres, and when the bait is raised the glass is drawn up with it. After the draw starts the cylinder is distended to the required diameter by the introduction of compressed air. In England cylinders are made in this manner some 40 feet in height, and uniform in both diameter and thickness. In America a height of 50 feet is reached.

Clearly it is a very delicate job to lower glass cylinders of this size to the ground, and to do so safely requires an intricate arrangement of ropes, pulleys and rigging. With the help of these the cylinders are brought down on to racks or rests standing in front to receive them.

The cylinder process, even when operated by mechanical means, has great shortcomings and disadvantages. The lowering, splitting, and flattening of the cylinders are all troublesome and clumsy survivals. It therefore became obvious that the logical way of making sheet glass was to produce it in a flat form from the outset.

Fourcault Process. In 1901 a patent for the mechanical drawing of sheet glass was taken out in Belgium by Emile Fourcault. Several years of experiment and development followed this first patent, and it was not until 1914 that commercial operation on a large scale became possible. In that year eight machines were installed at the Verreries de Dampremy, near Charleroi in Belgium, which had also been the scene of most of the experimental work. The installation continued to be operated with entire success throughout the difficult war period. After the Armistice the process was widely adopted in a number of window-glass factories in the United States.

The basic principles of the Fourcault process are extremely simple. A refractory block in the shape of a box with a slot in the bottom is placed in a tank of molten glass, and, being made of material of lesser density than the glass, it floats on the surface. When



Courtesy of The Institution of Mechanical Engineers

FIG. 23

MACHINE CYLINDER SHEET GLASS PROCESS

Second stage, showing the fully extended cylinders, and in the foreground one of the racks or rests on to which the cylinders are lowered.

pressure from above is applied to the block it becomes partly immersed. The slot in the bottom is now below the surface, and the pressure of the surrounding glass forces some of it upwards through the aperture towards the level of the main body of metal.

Fourcault arranged that immediately the glass had passed through the slot it should be cooled and drawn up between asbestos-covered steel rollers. More glass is continually being forced upwards, and, being cooled in turn, becomes sufficiently rigid to draw still more after it. It will be seen that in this way a curtain or sheet of glass is obtained as wide as the slot in the refractory block is long. As experience became available and technique improved, it was found possible to vary to a very considerable extent the thickness of glass produced. By drawing out the metal rapidly thin sheets were obtained, and by slow drawing thicker ones resulted.

When the Fourcault machine is working at maximum speed it can now produce approximately 550 sq. ft. of glass per hour.

The great disadvantage of the Fourcault process is that the sheet of glass has to continue to be drawn up vertically after it leaves the furnace. The curtain of glass takes some time to cool and become set, and as the drawing process must not be interrupted or stopped, the sheet has to pass upwards through two or three floors, a considerable height, before it is fully annealed and ready for cutting off.

Libbey-Owens Process. In the Libbey-Owens process further interesting advances have been made. The outstanding difference from the Fourcault method is that the ribbon of glass is re-heated shortly after leaving the furnace and is turned at right-angles so as to continue horizontally. The drawing system is also different, for the Libbey-Owens machine first lowers a bait of iron about 3 in. wide by 6 ft. long into the molten mass of glass, and then by reversing the motion pulls or draws the plastic glass upwards. The strip of glass is from six to eight feet wide, and if drawn at a speed of from 40 to 60 inches per minute the usual window glass thicknesses result. If the machine is operated at about 23 inches per minute a quarter-inch thickness is obtained, and slower speeds will give up to nearly half-inch thickness of glass.

When the Libbey-Owens machine is worked at the higher speeds it will produce 30,000 sq. ft. of glass in 24 hours, equivalent to 1,250 sq. ft. per hour. It has been estimated that this compares with 160 sq. ft. per hour turned out by an individual hand blower, and about 750 sq. ft. per hour by the machine-blown cylinder process. (See the frontispiece for illustration of the Libbey-Owens process.)

CHAPTER XV

PLATE GLASS

In the making of plate glass, evolution does not seem to have been taking place so rapidly as in the case of sheet glass. Cast or plate glass was being made in Lancashire at a very early period. It is interesting to note that the central aisle of the old casting hall at St. Helens has been preserved on account of its historical associations. It was here that her late Majesty Queen Alexandra, then Princess of Wales, saw glass made in 1865. The old method of casting is still the usual one to-day, although during the past few years changes of an important nature have been taking place. For the making of plate glass a crucible containing about a ton of molten glass is removed from the melting furnace and poured out upon a metal table. An immense heavy roller then moves across it, flattening it into a broad plate. To begin with, plate glass is rough and translucent rather than transparent, and before being placed on the market requires to be ground and polished on both sides. At the largest English works the emery, sand, and other abrasives used in the grinding and polishing processes amount every year to 150,000 tons. When, just before the war, the firm built a new extension works, they chose Cowley Hill, near St. Helens, as the site, in order that this huge quantity of waste abrasives might be deposited round the premises to form flat land.

Somewhat closely allied to plate glass as regards manufacture is the casting of large lighthouse and other lenses. With them a mould gives the shape, and subsequent cutting and polishing provide the finished appearance with which we are familiar.

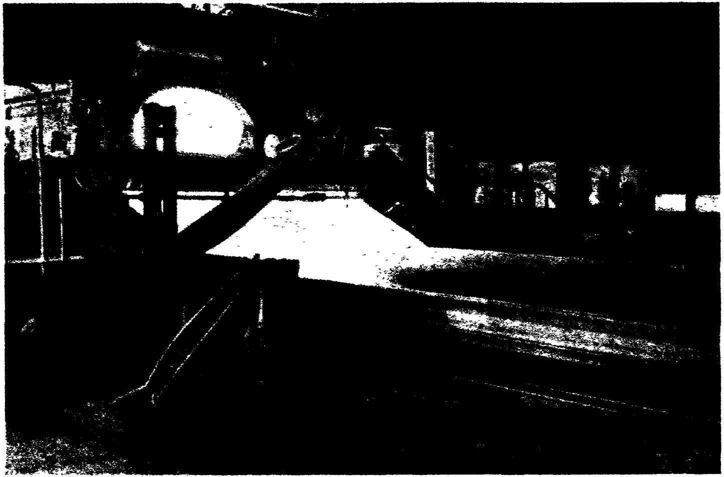
Ford Process. The Ford Motor Company use an enormous quantity of plate glass for wind-screens, etc. The glass is produced at a special plant, the River Rouge Works, erected in 1923. This glassworks consists of a building 760 ft. long by 240 ft. wide, housing four complete units for the manufacture of plate glass by the special Ford continuous flow method. Each unit consists of a glass-melting furnace of about 400 tons capacity, together with an annealing lehr 442 ft. long, 86 grinding machines, and 72 polishing machines. The total productive capacity of the four units amounts to about 10,000,000 sq. ft. of polished plate glass a year.

Each furnace at the River Rouge plant melts about 40 tons every 24 hours, consuming about 520,000 cubic ft. of gas in that time. Approximately 7 sq. ft. of glass is produced every minute. The glass emerges in a continuous ribbon and is cut off into sections the size of the grinding tables. Each sheet is just large enough to make three complete Ford wind-screens. In the rough, one of these sheets weighs 75 lb., but after grinding and polishing the weight is reduced to 51 lb.

Grinding. In the grinding and polishing process seven grades of sand are used one after another, and each on a separate machine. After use the sand and water are pumped back into a grading tank. Nothing is allowed to go to waste on the Ford plant, and accordingly in the case of sand each grade is used again a step down the scale, except the finest of all, in which the abrasive property has become quite exhausted.

When the sand-grinding process is complete the plates move under another series of machines for emery grinding. Five grades of emery are employed, from coarse to fine, and, as with the sand, the emery is re-graded and used again.

After the emery grinding, the glass is examined for



Courtesy of The Institution of Mechanical Engineers

FIG. 24

BICHEROUX PLATE GLASS PROCESS

The knives for dividing the ribbon of glass into sections will be noticed suspended just above where the glass flows on to the level.

defects, and, still on the same travelling tables as at the commencement, is moved on to the polishing machines, where rouge is applied. Up to this point only one side of the sheet has been treated. Accordingly it is now reversed and the operations repeated on the other side, after which the sheet is ready for use.

Bicheroux Process. The Ford process represents the most advanced American practice in the manufacture of plate glass. In Europe also there has been constant research, and new systems of making are being evolved. New factories have recently been erected in France, and in Germany a significant advance has been made by an invention of Max Bicheroux of Aachen, a well-known German engineer and glass manufacturer. Bicheroux had as his first object the making of thin plate glass. He succeeded in doing this by cutting the plate into several sections while it was still being rolled, and carrying the separate pieces at once to the lehr. Short tables and travelling knives were employed. Even more striking progress came when Bicheroux made the revolutionary change of abolishing the travelling roller and the casting table proper.

By revolving the pot about an axis passing through the pouring edge the distance through which the stream of glass has to fall is lessened, and folding of the surface, overlapping, and inclusion of air bubbles, are eliminated.

It is claimed that by the Bicheroux process a pot containing 850 litres of glass yields about 60 sq. metres of rough plate, compared with 31½ sq. metres by other methods. In addition the variation in thickness in a plate nominally 11½ mm. thick amounts only to 0·6 mm., compared with 2·5 to 3 mm. by the older methods. This in turn makes less grinding necessary, and increases the efficiency in this respect, it is said, by 35%.

CHAPTER XVI

TUBE, CANE, AND CHEMICAL GLASSWARE

IN this country much tubing and rod are still made by hand, partly because of the large variety of diameter and wall thicknesses called for, which tend to make a machine designed for big production uneconomic.

Hand System. A ball of glass is gathered from the furnace on a blow-iron, and is rolled on a small iron table or marver to give it an even and slightly conical shape. After it has been re-heated in a "glory-hole," or small subsidiary furnace, this ball of glass is "stuck-up" on an iron post. The glass is then drawn out by the tube-drawer walking backwards from the post-holder, and blowing down his iron while he does so to maintain the air cavity in the tubing. By altering the speed of drawing an experienced man can draw tubes of various diameters with considerable accuracy. He also varies the size and shape of gathering for this reason, and is further assisted by a third man, who gauges the tubing with callipers while it is being drawn. This second assistant cools the tube by flapping the air near it with a sheet of leather, thus preventing it being drawn out to a narrower diameter than the one required. Glass rod is made in exactly the same way except that the drawer gathers on a solid iron.

Danner Process. It was only during the war period that a means of drawing glass tubing and rod automatically was evolved. Patents for the American Danner tube-drawing machine were taken out in 1917, and in a few years it displaced practically all hand workers in the tubing field in the United States. The

Danner process is unusually ingenious and possesses several quite novel features.

The glass is melted in a tank furnace of normal design, and flows from this into a conditioning chamber, where it is skimmed and its temperature accurately adjusted. It continues down a chute on to a slowly revolving hollow mandrel, the flow being regulated by a gate that can be raised or lowered. The mandrel is a clay sleeve mounted upon a hollow shaft, which is designed so that its axis can be tilted downwards to the best working angle, which is usually found to be about 20°. The stream of glass winds round the upper end of the mandrel and is given a downward axial flow by gravity. At the top, where the glass first impinges, spiral waves are visible, but these smooth out before it is drawn off at the end of the mandrel.

When tubing is being made, a stream of air is blown at a steady pressure through the hollow shaft into the interior of the tube. By shutting off this air the change-over from tube to rod making is effected.

The drawing apparatus is situated up to 200 feet from the furnace. The pulling device consists of two endless chains, which are each running on two sprockets, arranged one above the other. The chains carry asbestos pads so that the tubing shall not come in contact with the metal, and the distance between the upper and the lower can be adjusted to accommodate tubes of different diameters. A variable-speed motor controls the rate at which the tubing is drawn, and, together with the regulation of the air supply, largely determines the diameter obtained.

The tubing is fed centrally between the chains of the pulling mechanism by guide wheels, and is carried along the tube run from the furnace by a series of grooved pulleys, which not only largely prevent friction, but lessen the amount of pull necessary from the machine. In 1921 tubing was being drawn on the Danner machine at the rate of 140 ft. per minute, but this rate has since been greatly increased.

When it leaves the puller the tubing is automatically cut to any desired length and delivered to a rack. As a rule it is also gauged automatically and separated into series of sizes.

It should be noted that the machine method of making glass tubing is like the hand method, in that a long tube of small diameter is drawn out from a heavy cylinder of large diameter, but that the automatic process has the great advantage that once the various factors are properly adjusted the resulting tubing continues to be exactly the same.

Laboratory and chemical glassware consists of thin blown ware in the form of flasks, beakers, test tubes, etc., used in chemical operations. Most of these goods are blown in hinged moulds mechanically or automatically operated by the worker. The lips and flanges of the necks, are neatly formed afterwards by the edges being re-heated and worked to a form which allows them to pour cleanly, and prevent any fluid therein from running down the sides of the flask or beaker whilst in use. The heavier glassware, in the form of desiccators, measuring cylinders, specimen jars, and three-necked bottles, are made by hand-work. Chemical apparatus has necessarily to be made from a permanent, stable, highly refractory glass, so as to resist the solvent actions of mineral acids, alkaline solutions, and boiling water, as well as sudden changes in temperature.

The manufacture of tube and cane glass for various purposes forms a large and extensive portion of the glass trade. Considerable quantities of tube and cane glass in various sizes are used by lamp workers in the manufacture of certain forms of chemical apparatus and in filling electric light bulbs. By re-heating glass tube and working before a blow-pipe flame, the various forms of test tubes, pipettes, burettes, soda-lime U-tubes, and condensers are made. Generally, for chemical apparatus two classes of tube are made, one a soft soda tube, and the other, hard combustion tubing. Particular care has to be devoted to the grading and sorting of the various sizes. The bore of the tube, the thickness of the walls, and the outside width have all to be checked and the lengths classed accordingly.

In the manufacture of tubing, unless the glass is of large size or great thickness, it is not annealed, and shows a case-hardened condition which materially increases the strength of the tube to resist internal pressure, as is the case with boiler gauge tubing. In the manufacture of apparatus from tube and cane, care must be taken that the various pieces used in welding together the different portions of the apparatus are of the same temper and composition, and supplied from one source, so that they may join and work perfectly together.

The lamp worker or glass blower should take care to get his supplies from a reliable source, so that the glass pieces will be adapted to work together. Trouble occurs when odd tubings from various makers are worked together. The same applies to fancy glass working, where various coloured canes are worked into ornaments. Reputable firms can always supply from stock colours and tubing properly adapted for their specific purposes, and they take every precaution to see that the various colours join and work together. Supplies of glass rod can be had that will join on to platinum, nickel, iron, or copper wire with sound joints.

The manufacture of white opal and coloured cane and tube is carried out by methods similar to those used in ordinary cane and tube making.

We will now describe the manufacture of Filigree. This is rod or tube containing opal or coloured threads, either straight, spiral, or interlaced within a transparent glass; these threads follow the whole length of the cane or tube.

This curious form of glasswork was originated by the Venetians, who are exceptionally skilled in producing elegant and ornamental filigree-decorated glassware.

The method of producing filigree cane consists of first taking a number of short lengths of opal or coloured cane previously drawn and cut to about 6 in. lengths. These are then placed in vertical positions around the inner circumference of an iron cup mould, which may be about 5 in. in diameter. The opal strips of cane are supported vertically in small recesses provided in the rim of the mould at equidistant intervals. A ball of hot crystal glass is gathered on a pontil and is lowered into the inside of the mould; the hot metal, coming in contact with the opal strips of glass, adheres to them, and upon withdrawal the glass brings the opal strips away with it, arranged in sections round the circumference of the ball of glass. This is now re-heated and marvered until the canes or strips of opal are well embedded in the hot glass. Then the workman gathers another coating of hot glass over the whole, marvers it again into a cylindrical form, and then proceeds to draw it out as described for cane making.

If a spiral form of lines is desired, the workmen, whilst drawing out the cane, turn or twist the pontil and post in contrary directions. These rotations cause the opal veins or threads to assume a spiral or twisted form within the glass. Variously coloured canes may be used in the above process, and by placing them in alternate positions to the opal strips within the cup mould some very pretty and curious filigree work is obtained. These twisted filigree canes are used and manipulated over again in the process of making the various Venetian goblets and wine stems. Some fine effects in the application of filigree decoration can be seen in the specimens of Venetian glassware exhibited in the British Museum.

Millefiore work is produced by the workman first spreading a layer of an assortment of small coloured glass chips of varying sizes (between ⅛ and ¼ in. cube) over the face of the marver, and then taking a gathering of crystal metal on his blow-iron and rolling the ball of hot glass into the coloured mixture on the marver. The hot glass collects up a coating of the coloured chippings. It is then re-heated and again marvered, and another gathering of crystal metal is made, which incases the whole. This is then blown out and worked into some form of ornament, such as a paper weight, inkpot, or bowl. This work produces a curious result that shows blotches of colours embedded within the glass, the effect of which is increased if a backing of opal glass has been used in the first gathering: this shows the coloured effect against a white background.

Spun Glass. Another curious form of glass is the spun glass which is much employed in making fancy ornaments. Glass can be spun into a thread so fine and flexible that it can be worked into a fabric like any textile material. In this way, glass ties can be made by plaiting the spun glass threads into the required form. Spun glass fibre is employed in making the brushes used for cleaning metals with acids. Because of its greater resistance to acids than is shown by ordinary cloth, an endeavour is being made to use spun glass cloth in certain industries as a commercial application.

Spun glass is used for making a form of filter cloth which is being used successfully in filtering acid residues in certain chemical processes, and, no doubt, when the elasticity and strength of the glass threads can be more developed, the scope for its use in other industrial processes will be increased.

The method of making spun glass thread consists in melting the end of a plain or coloured glass rod (which may be square, round, or triangular in section) in a blow-pipe flame and grasping the end which is melting with a pair of pincers, drawing it out and affixing it to a wooden drum, which is turned rapidly away from the glass being heated. The drum may be 2 or 3 ft. in diameter, and as the glass is continually fed into the heat it is drawn out into a very thin thread by the rapidly revolving drum, and coiled up until a sufficient quantity has been obtained. The thread is then cut across the drum, collected, and used for plaiting or braiding into the fabric or cloth.

The iridescence and variety of colours yielded by the refraction of light between the glass threads give spun glass its peculiar effect, very evident when it is used in decorating small ornaments, such as forming the tails of glass birds.

Glass wool is made in a somewhat similar way, and is successfully used as a non-conductive packing material for insulation from heat.

Glass frost or snow is made by blowing small gatherings of glass out to a bursting point. These very thin shells are then crushed and the flakes collected, and used for such purposes as surfacing sand paper or decorating Christmas cards, being sieved to the requisite size and affixed with a siccative to the paper.

Dolls' eyes and artificial human eyes are made by well-trained operators working before a blow-pipe flame and manipulating tube and cane of delicately coloured tints to form the pupil and shell of the eye, the veins being pencilled on with thin threads of red-coloured glass. A considerable amount of skill and adaptation are necessary to do this class of work, and much depends upon the matching of the coloured cane glass used to give the natural effects. When properly made, so clever and natural are these glass imitations of the human eye that it is with difficulty that the ordinary observer can tell that they are not real. A skilled worker will make the artificial eye to fit the muscles of the socket and so move. In this way much ingenuity has been shown in fitting the eye sockets damaged during the war.

Aventurine is a golden-coloured glass containing minute yellowish spangles or crystals reflecting upon each other and giving its peculiar effect. This glass is obtained by the use of an excess of copper with strong reducing agents in the glass, whereby the copper is partially reduced within the glass, giving the pretty spangled effect. This glass is often used in the form of jewel stones, being cut and polished and fitted in ornaments. The process of making this glass was originated by the Italians, and for some time it remained a secret with them, and even now is styled "Italian aventurine."

Chrome aventurine is another form, giving a green, spangled effect. This is got by using an excess of chromium in the presence of reducing agents.

The successful production of aventurine depends upon slowly cooling the molten glass so as to assist crystallization.

Mica schist, or flake mica, is used to give another curious effect in glass. A gathering of some dark-coloured glass is rolled or marvered upon a thin layer of flaked mica, and then a further gathering or coating of clear crystal metal is made. The whole is then blown and formed into some fancy ornament or vase. When finished, the glistening mica flakes show through against the coloured background, giving a curious silvery reflection.

CHAPTER XVII

OPTICAL GLASS

THE manufacture of optical glass is an important section of the glass industry, and presents some of the most difficult problems with which the glass maker has to deal. It is in this section of the glass trade that applied physical and chemical science becomes of the utmost importance to the manufacturer. The production of optical glass is impeded by any defects which become evident in the structure of glass when examined under a polariscope. The presence of any striae, seeds, or stresses within the structure of the glass disqualifies it for any important optical work. It is a difficult matter to get pieces of optical glass only a few inches in diameter of the right optical constant and refractive index that are homogeneous enough to allow the light rays to pass without some dispersion when set up for use. It becomes necessary, therefore, to achromatize one glass with another in the form of doublets to correct aberration. A high degree of transparency and durability is necessary in all optical glasses.

The persistent evidence of stresses developed in the solidification of the glass upon cooling, even when the glass is slowly and carefully annealed, is a most difficult factor to deal with. In annealing optical glass, the various temperatures and time periods have to be delicately adjusted and controlled, or big losses result. Even then many efforts may be made before a suitable piece of glass is obtained, and the costs accumulate with each attempt, so that some idea of the amount of labour involved in the undertaking to produce optical glass at once becomes evident. The use of decolorizers and impure materials is not permissible, on account of the absorption and consequent resistance to the passage of light rays. The annealing, instead of occupying the normal time, is sometimes extended over a course of several days, in order gradually to relieve any stress present. The pots in which the glass is melted may only once be used, as the glass is usually allowed to cool down gradually and undergo the process of annealing within the pots.

The temperature of the furnace is controlled by regulating the draught by means of dampers in the main flues, arranged to act so as to carry out the annealing of the glass within the furnace. The regulation of the furnace temperature is very important; if the temperature is too hot the glass dissolves the clay of the pot, and if retarded too much it causes difficulty in freeing the metal from seeds, and plaining or fining the glass properly. Small furnaces containing one or two pots give the best results. These furnaces are worked on an intermittent process of first melting the glass and then gradually cooling to anneal the glass within the pots in mass, the furnace being allowed to die out gradually. When cool, the pots are broken away from the glass, which is then cleaved into lumps. Each lump is carefully examined for any defects and the best pieces selected for re-annealing. These are afterwards ground to the desired shape in the form of either a lens or prism.

The chances are that not many pieces of perfect glass can be obtained from each pot of metal, and probably out of a whole pot only a fifth will be suitable for use after the process of selection and cleaving has taken place.

In the manufacture of optical glass, batch materials are chosen that do not differ greatly in specific gravity. Every effort is devoted to obtain the purest materials possible; the batches are finely ground and well mixed before melting. The glass-melting pots should be made of the purest and most refractory fire-clay obtainable in order to prevent the solution of any impurities into the glass whilst it is melting. In heating the pots for melting optical glasses every endeavour is made to heat them equally all round the top, bottom, and sides, so as to dissolve all portions of the glass evenly and completely together. At times the melted glass is stirred with a bent iron rod encased in a porcelain tube, and the glass agitated in order thoroughly to mix the components whilst fusing, and keep the composition of the glass as uniform as possible. After the metal has melted and plained clear from all seed and cords, the pot of metal is annealed, and when cooled the glass is extracted in lumps and examined for any defective pieces, which are rejected. The selected pieces are afterwards ground to the desired shape and, if necessary, re-annealed. In this process the pots, being used only once, are expensive items, and they considerably increase the cost of production.

Before the war the optical glass trade was confined to a few firms in this country, who supplied only a fraction of our needs. We have been dependent mostly upon Continental supplies of optical glass, and it is only quite recently that Government assistance has been forthcoming in giving scientific aid to manufacturers by investigating and reorganizing this section of the glass industry. It is to be hoped that this State assistance will continue, and that the optical branch of the glass trade will be perfected to such an extent that we may in future be independent, and produce for ourselves all the optical glass requirements of our

Navy and Army. It is to be regretted that this industry did not receive State assistance before the war. If it had, we should certainly have been better prepared and equipped than was the case at the start of the Great War.

CHAPTER XVIII

DECORATED GLASSWARE

CERTAIN methods of decorating glass are carried out whilst the glass is being made by the workmen. Other methods consist in decorating the glass after it has been made, such as cutting, fluting, etching, engraving, and enamelling. In another form of decoration the method consists of a combination of two or more of the above processes. The crystal glass may be cased over with a thin covering of coloured glass by the glass worker, and this outer coloured casing cut through by the glass cutters, exposing and showing through the colourless crystal underneath with very effective results.

A small portion of coloured glass, such as citron green, topaz, blue, or ruby metal, is gathered from the pot by an assistant, and the workman, gathering a ball of crystal glass on his blow-iron, allows a portion of the coloured metal held by the assistant to fall or drop upon the ball of crystal. Upon blowing the whole out, the coloured metal is spread as a thin casing upon the outside of the bulb of crystal. This bulb is then worked into a wine-glass or other article, which, after annealing, is sent to the glass cutter, who decorates the outer surface by cutting the glass on his wheel. The colourless glass then shows through against the coloured surface where it has been cut to the pattern, the colour standing out in relief.

In another form of decoration, the workman allows small pear-shaped tears or drops of coloured glass to fall upon the outer surface of a bowl or vase, in equidistant positions round the circumference of the article.

By placing and working the coloured glass into position in this way, some pretty, artistic results are obtained, dependent upon the skill and artistic taste of the workmen.

In another method of decoration, certain coloured glasses are used, the composition of which causes them to turn opalescent when the glass is re-heated to a dull red heat. The re-heating of the tops of crimpled flower vases made from such glass gives pretty results, showing a gradual fading opalescence, extending from the top edges a few inches down the vase into a clear coloured glass at the foot of the stand. A similar effect, without the opalescence, is obtained by the workman gathering a small piece of coloured glass on the tip of his blow-iron, and then taking a further gathering of clear crystal metal. The whole is then blown out and worked into a vase or wine-glass, thus obtaining a coloration denser at the top edges, where the vase or wine-glass has been sheared off, and gradually fading away to a colourless glass a few inches towards the foot, which is clear crystal.

There are also certain compositions which, when worked into a vase, and re-heated on the edges, strike or turn to a colour such as pale blue or ruby. These are self-coloured glasses, in which the colouring remains latent until the glass is re-heated, like the opalescent glasses. In these glasses the composition is the chief essential factor.

Glass cutting is an effective way of decorating glassware. In using this method, the crystal glassware is made fairly heavy and strong, so as to permit of the deep cuttings which refract the light and show up the prismatic patterns so brilliantly.

In cutting glassware, the glass cutter works in front of a rotating disc of iron carried in a frame. This wheel has a bevelled edge upon which a fine jet of sand and water is allowed to drip from a tundish above. The abrasive action of the sand cuts into the glass, and the workman, by holding the glass dish or bowl against the wheel, follows the design or pattern in diagonal lines across the article. These cuttings are recrossed, and the intermediate diamond spaces filled in with lightly cut set patterns, until the whole of the intended design is "roughed" out over the surface of the glass, after which the glass is taken to another frame carrying a stone wheel, which is of much finer abrasive action. This stone wheel smooths the rough cuts done by the

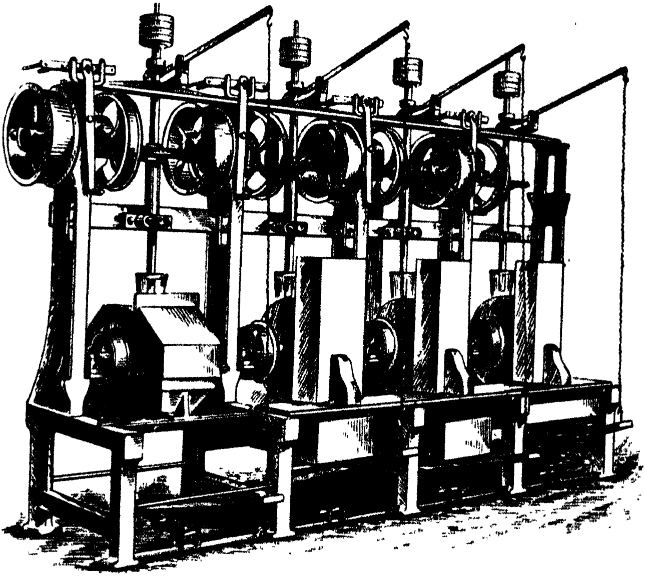


FIG. 25

MACHINE FOR SMOOTHING BOTTOMS OF TUMBLERS previous wheel. After this the cuts are polished successively on a wood wheel and brush with polishing powders, until smooth and polished cuts are obtained.

As the value of the glass is greatly increased by cutting, only the best and clearest articles of table glass are so treated. The work of cutting becomes delicate and expensive, according to the richness of the cutting demanded. The crystal table glass made from lead gives the most brilliancy in cutting. Soda-lime glasses are found to be hard to cut, and do not give such brilliant and prismatic effects as the glass made from lead compositions.

An automatic machine for grinding, smoothing, and polishing the bottoms of tumblers, etc., "bottoms" or grinds, smooths, and polishes tumblers at the rate of 2,000 a day. Four vertical revolving wheels are fixed within a frame, one iron, two stone, and one wood. Over each of these is a rotating spindle carrying the tumbler so that the bottom of it is automatically pressed against each vertical wheel in turn. The first wheel does the roughing, the two next the smoothing, and the fourth the polishing. These machines are simple and require only unskilled labour to operate, and go far towards cheapening production.

Glass engraving and intaglio work are much lighter and more artistic methods of decorating glass than the deep cutting before described. In these processes the glass is cut or ground to a less extent, and a more free treatment of design is possible. Floral ornamentation and natural forms of applied designs can be carried out, and portions may be left rough or polished, according to the effect of light and shade required. The workman, whilst engraving, works before a small copper or metal wheel rotating in a lathe, and uses fine grades of emery or carborundum powders made into a paste with oil as the abrasive medium. The frame turning these wheels is like a lathe, and may be worked by a foot treadle. The wheels are interchangeable, and an assortment of various sizes, having different bevelled edges, is kept at hand in a case, from which the engraver selects the one most suitable for the particular work to be done.

Glassware for engraving and intaglio may be made much lighter than that required for cutting.

Etching is a method of decorating glass by the chemical action of hydrofluoric acid. This acid in its various combinations attacks glass, decomposing its surface and giving a dull or semi-matt effect. Only those portions of glass which constitute the design are exposed to the acid paste or fumes. The other portions of the glass are coated with beeswax, which is unaffected by the acid and protects any portions covered by it.

The process carried out is varied in many ways. In some cases pantograph and etching machines are introduced to give the designs. A warm copper plate, with the design or ornament engraved thereon, is covered with a wax paste, and the surplus cleaned off with a palette knife or pad of felt, leaving the paste in the recesses of the engraving; a piece of thin tissue paper is laid over the engraved plate and takes an impression of the design in wax. This tissue is then transferred to the glass to be decorated, the wax design adheres to the glass, and the paper is drawn away. A further resist or coating of wax is painted round the design to protect the rest of the glass, and a paste composition giving the action of hydrofluoric acid is applied, which after a short time eats into the exposed portions of glass. After another short interval, it is washed off, and the wax coating removed by washing

FIG. 26.

GLASS ENGRAVING

the glass in hot, soapy water. The design then appears in a matt state against the clear, unattacked glass.

The mechanical method of etching the design is carried out by first dipping the whole glass into a bath of hot liquid wax, allowing a thin coating to set and cool upon the surface of the glass. The article is then introduced into a machine which has a number of needles, worked by sliding gears in an eccentric fashion. These needles are adjusted just to scratch away the thin coating of the wax into a design, and expose the glass in the form of a decorated scroll or band round the glass. The glass is then dipped into a vat or bath of dilute hydrofluoric acid for a few minutes, after which it is removed and washed, and the wax recovered by heating the glass upon a perforated tray, when it melts and runs off the glass, and is collected for further use. The article is then washed and cleaned and shows the scroll or etched portions where the needle has traced the design. Another effective result is obtained by etching a design on the back of a plate glass panel. After cleaning and silvering or gilding the back, the design appears in a matt silver or gilt lustre upon viewing it from the front of the mirror.

Glass which has been sand-blasted has a similar appearance to etched glass, but a rather coarser surface. The portions of the glass plate to be decorated are exposed to the action of a blast of air, into which fine, sharp-grained quartz sand is automatically fed. An abrasive action, due to the force with which the particles of sand are blown against the glass, takes place, rendering the surface opaque or matt. This method is generally adopted in printing trade names or badges upon bottles, etc. A stencil of parchment or lead foil is cut out to form, and used to protect the glass and resist the abrasion where required. Rubber gloves are worn by the operator. The work of sand-blasting is executed within a small enclosed dust-proof chamber fitted with glass panels. The operator manipulates the glass through openings in the sides of the chamber. The air blast is supplied by a motor-driven air compressor and is regulated by a foot pedal. The action is very sharp and quick, and is a cheap and effective way of badging hotel glassware and proprietary bottles.

Glassware may be decorated by being enamelled with coloured enamels. In this method of decorating, soft, easily-fused, coloured enamels are used, containing active fluxes such as borates of lime and lead, which melt at low temperatures. These enamel colours are prepared by being fused and then ground to fine powders, which are mixed with a siccative or oil medium, and painted upon the glass. The painted ware is then heated within a gas or wood-fired enamelling furnace or muffle, until the painted designs are melted and fused well upon the glass. The glass is re-annealed in cooling down the muffle. For this form of decoration, a hard refractory glass is required that will not soften easily under the heat of the muffle; otherwise the glassware becomes misshapen too easily under the heat necessary to flux or fuse the enamels properly.

A form of staining glass is also practised which consists of applying compositions containing silver salts to portions of the glass, and firing at a low heat. The silver stains the glass a deep yellow. The colour may be varied by the use of copper salts, when a fine ruby stain is obtained wherever applied.

Iridescent glassware is produced by several methods. Sometimes a small proportion of silver and bismuth is added to a coloured glass batch, and by manipulation of the resulting glass in a carbonaceous flame the silver is partially reduced within the glass, forming a pretty iridescent reflection on the glassware. By a suitable adjustment of the oxygen content in the composition of such glasses, the iridescence can be regulated to such an extent that the slightest flash or reducing influence gives a beautifully finished lustre over the ware.

Iridescence can also be formed by re-heating crystal glassware within a chamber in which salts of tin, barium, aluminium, and strontium are volatilized. This method produces a superficial iridescence which is not quite so permanent as that obtained by the previous process.

Glass Silvering. The silvering of mirrors is carried out by taking a thoroughly cleaned plate of polished glass and floating one surface in a solution of silver nitrate, to which a reducing agent is added. The silver is thereby precipitated or deposited in a thin lustrous film upon the glass, which causes reflection by the rays of light striking against the silvered background.

After silvering, the back of the plate is coated with a protecting paint or varnish, which dries and preserves the silver deposit and gives it permanency.

In the manufacture of fancy ornaments, such as birds, hat-pins, and small animals, various coloured glass cane and tube are worked by the operator melting and welding the respective colours together with the aid of a blow-pipe flame, the tails of the birds being formed by sealing a fan of spun glass into the body of the bird, which has been blown out and formed from a piece of tube. Some very curious ornaments are formed in this way. Glass buttons and pearl and bead ornaments are formed by working cane and tube of various coloured compositions before the blow-pipe, sticking and shaping the various forms on to wire.

Mosaic glass decoration is used in jewellery in a mural or tessellated form. In this method small cubical or other shaped cuttings of various coloured opaque glass are inlaid in mastic cements or pastes to form the design, the face being afterwards ground and polished smooth, and mounted or set within the ornament.

Larger cuttings may be inlaid in cement for pavement or mural decoration.

CHAPTER XIX

THE GEOGRAPHICAL DISTRIBUTION OF THE INDUSTRY

The United States. Fine cut glass is now a somewhat unfashionable luxury in America. This results partly from the difficulty of securing suitable domestic service, which has caused many of the wealthier citizens to live in hotels and clubs, and partly from the great use of the motor-car, which takes the housewife so frequently away from home that a large proportion of meals are obtained in public places. In addition presscut tableware has become so cheap that even the coloured people are able to buy it, causing it to fall into disfavour elsewhere.

Glass Bottles. The largest use of glass bottles in the United States is for the household distribution of milk and cream. The delivery of milk to the urban population by bottles is practically universal, and half the total number of inhabitants live in the towns. It follows that as the annual consumption of milk, according to the United States Dairy Department, is about 56 billion pints, no less than 28 billion pints are distributed each year in bottles. An expert investigator has estimated that the output of milk bottles in the United States is about 1,400,000 gross yearly.

The second greatest use for bottles in the States is in connection with mineral waters, including flavoured and unflavoured soda waters and beer, which, since Prohibition, have been required by law to have not more than ½ per cent alcoholic content, and which, therefore, fall strictly in the mineral water category. Bottles up to five gallon capacity are also largely used for storing fruit juices and concentrated "soft" drinks required in soda fountains and drug stores.

The bottling of preserves and fruits increased nearly three-fold between 1914 and 1919. The domestic use of jam is, however, much less than in this country. It is the rule for fresh fruit and cereals to be taken at breakfast, and as there is no meal corresponding to the English tea, there is little or no place for jam. Hence the number of jam jars manufactured is smaller than might be expected.

Fear of Over-production. There is fear in the States of over-production of glass. Automatic machines have been evolved which are so highly productive that even the immense consuming power of the American continent has not proved adequate. In one works it was stated recently that a production had been attained of 1,100 gross of 14 to 16 oz. jars from one furnace in a single day, equal to more than 900,000 jars in a six-day week. And the firm were operating a number of other furnaces.

The application of machinery to glassmaking has, in fact, been carried very far in the United States. At one factory tumblers are produced at the rate of about 35,000 per machine per day; at another the daily output of electric bulbs has reached as many as 60,000 per machine. It will be seen that the number made in the course of a twelvemonth is stupendous. The demand for plate glass is extremely large. Each year over four million automobiles are produced, of which even the open touring variety require wind-screens, apart from the rapidly growing proportion of saloon cars, which require much more plate glass.

Germany and Czechoslovakia. Germany and Czechoslovakia have many of the best equipped glass manufacturing plants in Europe. While in some cases wages are undoubtedly low, the factories are situated in country districts where the cost of living is correspondingly low. It is evident, in fact, that the low price of German glassware is the result of the use everywhere of the very latest scientific equipment and knowledge, combined with a high degree of organization for large output. The quantity of glass being produced makes it possible for an elaborate cut design, for example, to pass through a number of hands, each person repeating endlessly one small part of the work. Unskilled workers, often young girls, by always cutting the same part of the design in this way can produce together a richly cut article which would call for much skill if made by any single individual. The rate of working, both at the furnace and during the finishing processes, is very rapid, and it can clearly be seen that those employed are healthy and contented. The lighting and general cleanliness of the factories are in many instances examples to British manufacturers.

Importance of Research. In one German electric bulb works the administrative block of buildings has two floors allocated to laboratories and one only to the office, a striking example of the importance attached to scientific research, and an indication of the necessity of supporting to the utmost the fine work of the Society of Glass Technology in this country. Not only is an immense amount of tableware exported from Central Europe to nearly every part of the world, but almost all other kinds of glass as well. The output of the German Osram company, which is partly for export, has, for instance, reached 3 to 3½ millions of electric bulbs, and 65,000 lb. of glass tubing and rod, per week.

France. Many people consider that French artistic glass, for both ornamental and table use, is the best that is being made to-day. Much of it is sold in England at high prices, certainly often at many times the cost of production. It is true to say that in Europe as a whole the market for cheap fancy and utility glassware is supplied by Germany and Czechoslovakia, and for the more expensive classes by France.

The moulded glassware of Lalique, often in beautiful colour schemes and frequently showing marked originality in conception, is very popular in England. It is claimed that only a limited number of glasses of any one design are made, after which the mould is broken up. To some extent the Lalique glasses have, therefore, a rarity value.

Belgium. Belgium is a very large producer of window glass, which she exports in great quantities to the United States, Great Britain, and elsewhere. In one Belgian window glass factory, where the Fourcault process is being operated, it is proving possible to produce a rapidly increasing range of thicknesses in sheet glass. When a new thickness is produced it is first sent to the factory's agents in China. When the Chinese are fully satisfied with the quality, the glass is placed on the English market! By thus eliminating defects before competing in our market a reputation for good quality has been earned over here. In America the building programme has been on so vast a scale for a number of years that the demand for sheet glass has been far in excess of home supplies. In the erection of a single sky-scraper the amount of glass used is far from negligible. Each year there has been an import balance of about 25 million dollars worth of window glass into the States, and the bulk of this came from Belgium.

The Compagnie Internationale pour la Fabrication Mecanique du Verre, at Moll (Belgium), has made excellent provision for the large production necessary to supply a world-wide trade. Three 1,200-ton tank furnaces, each provided with two drawing machines and two lehrs, are being worked with almost an entire absence of manual labour.

The manufacture is also carried on in Belgium of artistic glassware similar, but somewhat inferior, to that produced in France. A speciality frequently to be seen in the shops of Brussels and Antwerp is gaily coloured suites of cut glass, not always in very good taste.

The Netherlands. National characteristics show themselves sometimes in unexpected ways. Thus the marked simplicity of Dutch middle class tables results in there being no demand in Holland for expensive domestic glassware. The small quantity of cut and decorated tableware used by the more wealthy inhabitants is mainly imported from France and Czechoslovakia. In the wine services made locally artistic expression is found in shape rather than in cutting.

Before the war there were eleven bottle factories in the Netherlands, having a production of 100,000,000 bottles per annum. This output has since declined considerably, the chief cause being the prohibition of the export of gin to the West Coast of Africa.

Sheet glass is being more and more employed owing to the increasing horticultural area under glass. Intensive market gardening in frames and greenhouses is one of the chief occupations of the country, and in going by road from place to place in Holland one is impressed by what seem the countless acres under glass.

Japan. In recent years an important glass industry has grown up in Japan. There is a large demand for bottles as containers for beer and "saké," a drink prepared from rice. The bottles are supplied entirely by local manufacture, and in addition there is a considerable export of them from Japan to China, the South Seas, and India. The export to India has, however, largely decreased since the war time.

Beer bottles were made entirely by hand in Japan until 1917, when the Owens Machine Bottle Manufacturing Co. of America sold the rights to use their machines in Japan to the Nippon Glass Co., who immediately installed their largest and most improved type of automatic bottle-blowing machines. These machines practically eliminated the hand manufacturer. The four works of the Nippon Glass Co. have a maximum output capacity to-day, it is said, of 200,000,000 bottles per annum. With the exception of soda ash, all the raw materials for this vast production are obtained from Japanese sources.

The section of the glass trade growing most rapidly in Japan is that dealing with sheet and plate glass, the annual increase in the demand for which is said to be from 5 per cent to 10 per cent. This is accounted for by the growing popularity of glass for use in Japanese houses and by the increase in the number of large office buildings.

There is also a large demand for polished plate glass for mirrors, show windows, and motor-cars. The entire consumption is imported, the imports into Yokohama alone amounting to about 100 cases a month. The principal countries that supply are Belgium, France, Czechoslovakia and Germany.

The importation of domestic and fancy glassware into Japan is very small, what there is being mainly from Belgium. There is a small but increasing demand for good quality tableware among the foreign residents and the wealthy Japanese, who live or entertain in the European manner.

Scientific glassware, for surgical and laboratory purposes, is made in numerous small factories in Tokyo. This type of glassware is exported to China and America, as prices are much below British or American on account of the low wages paid in this branch of the industry in Japan. The glasses are all blown by hand without the aid of machinery.

A glass factory at Osaka, making pressed glassware of all kinds, including tumblers, tableware, and ornamental bowls, has a yearly production of 9,000,000 dozen articles. A fair export business in these is maintained with India, the Dutch East Indies, and Australia. The city of Nagoya produces small glass bottles to the yearly value of 800,000 yen, of which 60 per cent is exported to India and the Dutch East Indies.

The Indian Markets. The Japanese hold on the Indian markets is no longer secure, however, for since the war a number of glass factories have been built in India on modern lines. Those in charge of the new plants are in a number of cases Indians who have had the advantage of an English training in glass technology under Professor Turner at the Sheffield University. It may be expected that distance alone will quickly make it difficult for Japanese and European manufacturers to compete with the home industry in India. A serious disadvantage from the Indian point of view, on the other hand, is the shortage of good coal, which is found only in Upper Assam, Western Bengal, and the Deccan. The position is in some respects analogous to that of the cotton industry, except that glass is naturally not used in bulk by the natives.

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